PARTS OF THE ORIGINAL DOCUMENT

ARE OF POOR REPRODUCTIVE QUALITY

CERTAINES PARTIES DU DOCUMENT ORIGINAL

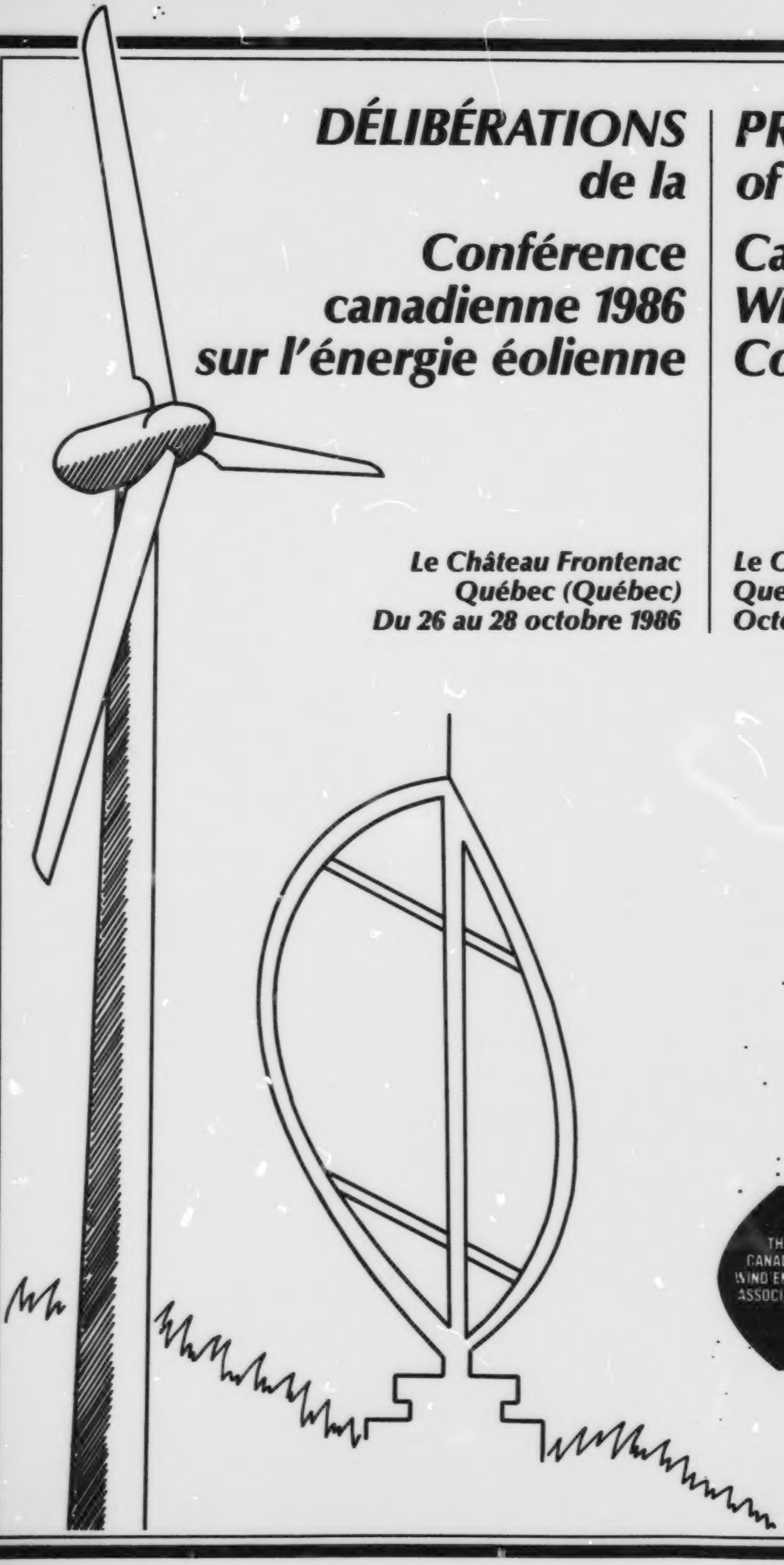
SONT DE PIÈTRE QUALITÉ DE REPRODUCTION

DÉLIBÉRATIONS de la Conférence canadienne 1986 sur l'énergie éolienne

Le Château Frontenac
Québec (Québec)
Du 26 au 28 octobre 1986

PROCEEDINGS of the Canadian Wind Energy Conference '86

Le Château Frontenac
Quebec City, Quebec
October 26-28, 1986



THE
CANADIAN
WIND ENERGY
ASSOCIATION

PROCEEDINGS OF THE SECOND NATIONAL CONFERENCE
OF THE
CANADIAN WIND ENERGY ASSOCIATION (CANWEA)

Quebec, Quebec

October 26 - 28, 1986

Edited by:

Vince Lacey

Produced by:

Passmore Associates International
Ottawa, Ontario

Sponsored by:

Energy, Mines and Resources Canada

Ministère de l'Énergie et des Ressources
Gouvernement du Québec

February 1987

ACKNOWLEDGEMENT

The Canadian Wind Energy Association (CanWEA) would like to thank all of those who devoted their efforts to make this second conference of our newly formed association a success:

Vince Lacey of Indal Technologies and Malcolm Lodge of Resource Ventures Inc., who coordinated much of the program planning;

Albert Watts of Institut de Recherche d'Hydro Québec, who managed the financial activity;

Alex Printzios of Adecon Energy Systems, who chaired the conference;

Passmore Associates, our conference organizers, who exceeded our demands for an efficient and smoothly run conference; and

our generous sponsors, Energy, Mines and Resources Canada and the Ministère de l'Énergie et des Ressources, Gouvernement du Québec, who made the conference possible.

Our many thanks to our loyal members who attended, many of whom presented interesting and informative papers; to the exhibitors; and to our American Wind Energy Association (AWEA) colleagues who visited us.

PROCEEDINGS AVAILABLE FROM:

The Canadian Wind Energy Association (CanWEA)

44A Clarey Avenue
Ottawa, Ontario
K1S 2R7

(613) 234-9463

CANADIAN WIND ENERGY ASSOCIATION
SECOND ANNUAL WIND ENERGY CONFERENCE

PROCEEDINGS

TABLE OF CONTENTS

PAGE

Introduction v

R.J. Templin Award vii

OPENING ADDRESS

Don Strange, Director General, Renewable Energy Branch, EMR 1

TECHNICAL PAPERS

THE COMMERCIAL MARKET

THE COMMERCIAL MARKETPLACE IN ALBERTA
Dale Johnson, Wind Power Inc. 5

NON-CONVENTIONAL FINANCING OF CANADIAN WIND PARKS
J.C. Shepherd, Blaney, McMurtry & Partners 19

WIND AND ELECTRIC UTILITIES: A VIEW FROM ONTARIO
Amir Shalaby, Ontario Hydro 37

COMMERCIAL WIND ENERGY ACTIVITY IN THE UNITED STATES
Tom Gray, American Wind Energy Association 47

THE POLITICS OF COMMERCIALIZATION
Jeff Passmore, Passmore Associates International 51

RESEARCH AND DEVELOPMENT

ANALYSE MODALE DE L'ÉOLIENNE 50 KW DE L'IREQ
H. Pastorel, W. Heilmann, B. Saulnier, F. Léonard
Institut de Recherche d'Hydro-Québec 65

DYNAMIC-STALL MODELS FOR DARRIEUS ROTORS
Ion Paraschivoiu, Azeddine Allet
École Polytechnique de Montréal 83

UN MODÈLE DE SILLAGE POUR LES ÉOLIENNES DARRIEUS ET SON APPLICATION AU CALCUL DES FORCES INSTATIONNAIRES
Bernard Massé, Institut de Recherche d'Hydro-Québec
A. Laneville, P. Vittecoq, Université de Sherbrooke 107

DESIGN OF GEAR-LESS WIND TURBINE VARIABLE SPEED GENERATORS
J. Hylander, Chalmers University, Sweden 123

MECHANICAL AND PUMPING APPLICATIONS

NEW DEVELOPMENTS IN CANADA IN WIND POWERED WATER PUMPING
Jason Edworthy, Nor'Wester Energy Systems Ltd. 135

OPTIMIZATION OF WIND PUMPING RESERVOIR CAPACITY
E.J. Schiller, University of Ottawa 159

A TWIN-AIRFOIL TYPE, OSCILLATING BEAM, WIND-DRIVEN WATER PUMPER
J.A.C. Kentfield, University of Calgary 175

PERFORMANCE TESTING OF THE DELTX WP-20
D. Baker, DRB Engineering Consultants Ltd. 189

POSTER SESSION

FLOW VISUALIZATION FOR AN OSCILLATING PROFILE IN A SIMILAR MOTION WITH THE DARRIEUS TURBINE
Philippe Fraunié, I.M.S.T. France 203

ATLANTIC WIND TEST SITE ACTIVITIES
Carl Brothers, Atlantic Wind Test Site 229

INITIAL DATA FROM A SURVEY OF WIND TURBINES INSTALLED IN CANADA
David Hoffman, World Wind Communications Co. 249

A MICROCOMPUTER VERSION OF A THREE-DIMENSIONAL WIND FLOW MODEL FOR USE IN COMPLEX TERRAIN
J.R. Salmon, Environment Canada 253

WIND-TUNNEL MODELLING OF ATMOSPHERIC BOUNDARY-LAYER FLOW OVER AN ISOLATED HILL
Mohamed Shokr, Atmospheric Environment Service 267

ALIMENTATION HYBRIDE EOLIENNE-DIESEL D'UN EMETTEUR RADIO
J.-M. Arseneault, Y. Jean, C. Jolicoeur, G. Turgeon,
Université Laval 279

BANQUET ADDRESS

Monsieur Alban D'Amours, Ministère de l'Énergie et des Ressources
Gouvernement du Québec 289

DEMONSTRATION PROGRAMS

FORT SEVERN WIND/DIESEL PROJECT UPDATE
Per Drewes, Ontario Hydro and D. Hume, Howden 309

PROJECT EOLE UPDATE
G.H. Beausoleil, Shawinigan Consultants Inc. 313

WIND/DIESEL POTENTIAL FOR REMOTE POWER SYSTEMS - TECHNICO-ECONOMIC ASPECTS
Réal Reid and Bernard Saulnier,
Institut de Recherche d'Hydro-Québec 329

TECHNOLOGY DEVELOPMENTS

INCREASED OUTPUT FROM DARRIEUS ROTORS
D.J. Malcolm, Indal Technologies Inc. 367

OPTIMIZATION IN WIND TURBINES
John Ereaux, Adecon Energy Systems Inc. 373

A WIND TUNNEL INVESTIGATION OF AEROBRAKES FOR VERTICAL AXIS WIND TURBINES
Paul Penna, National Research Council Canada 381

WINDFARM COUPLING TO ONE DIESEL SET
Jean-Marc Noël, Aerowatt-International 391

WIND ENERGY STANDARDS

CSA STANDARDS PROGRAM ON WIND ENERGY
Brian Weir, Canadian Standards Association 409

EVALUATION OF CSA PERFORMANCE STANDARDS
Carl Brothers, Atlantic Wind Test Site
Dave Baker, Lethbridge Test Centre 415

WIND POWER IN ALBERTA TWENTY-ONE MONTHS AFTER THE DECISION
H.D. Miller, TransAlta Utilities 425

GOVERNMENT AND INTERNATIONAL AFFAIRS

THE CANADIAN WIND ENERGY R&D PROGRAM
Monique Carpentier, Energy, Mines and Resources 435

AEI-USDA WIND ENERGY PROGRAMS 1985 - 86
Vaughn Nelson, West Texas State University 445

WIND ENERGY ACTIVITIES IN SWEDEN
Staffan Engström, National Energy Administration, Sweden 449

Index by Author 453

ATTACHMENTS

List of Attendees 455
List of Exhibitors 463
Minutes of CanWEA Second Annual Meeting 465
Minutes of CanWEA Directors' Meeting 479

CANADIAN
WIND ENERGY
ASSOCIATION

44A Clarey Avenue
Ottawa, Ontario, K1S 2R7
(613) 234-9463

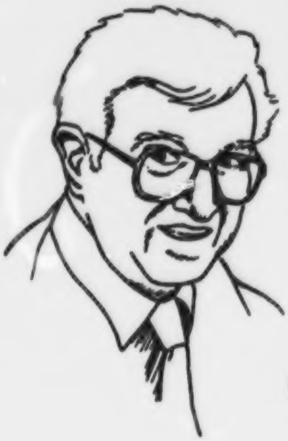
INTRODUCTION

The long-term growth and advancement of wind energy has been and continues to be the primary challenge that fuels the Canadian Wind Energy Association (CanWEA).

This second CanWEA conference represents a clear indication that this challenge is being fulfilled at a steady pace - each step bringing us closer to our goal.

We must now look at the future with confidence, knowing that the seeds that we have sown today will undoubtedly result in wind power earning its rightful place in the energy sector.

Alexander Printzios
President 1986

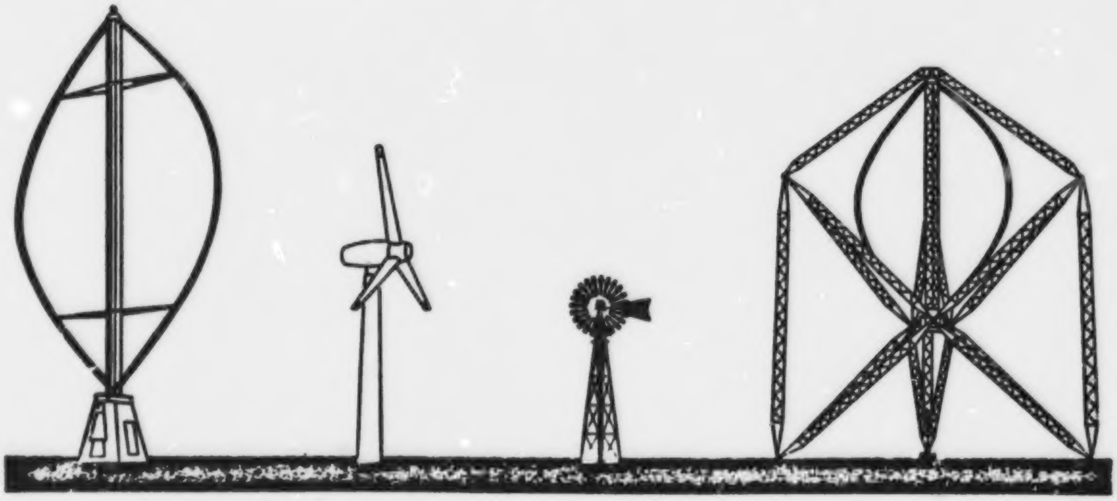


The
R. J. TEMPLIN
AWARD

For outstanding contributions
to the development of
Canadian wind energy technology

To

R.J. Templin



Presented by:

The Canadian Wind Energy Association
2nd Annual Conference, Quebec City, Quebec
October 27, 1986

OPENING ADDRESS

OPENING ADDRESS - CANWEA

Dr. Don Strange
Director General
Renewable Energy Branch
Energy, Mines and Resources

I wish to thank you for the opportunity of addressing this conference and I take it as an honour to be able to speak to such a dedicated group of people.

There are basically three elements of my short presentation today.

1) I want to talk briefly about the encouraging developments taking place in the wind business;

2) I will then discuss the problems that have to be resolved;

3) Finally, I will summarize where EMR is going in the renewable energy area.

Mesdames et Messieurs, je suis très encouragé par les efforts et les réalisations dans le domaine de l'énergie éolienne de ces derniers mois. La cessation des activités dans le domaine des éoliennes du Conseil National de Recherches a été regrettable. Par contre, en revisant ce qui a été accompli depuis, nous avons raison d'être optimistic. Par example:

1. L'Association elle-même (Association Canadienne de L'Énergie Éolienne

Les progrès réalisés par l'Association Canadienne de l'Énergie Éolienne sont remarquables. Après seulement deux annees d'existence, l'association a su encore une fois regrouper les principaux intervenants en énergie éolienne sous un même toit. L'élément qui a mené à ce succès est sans doute l'effort concerté de tous les participants envers la cause de l'énergie eolienne au Canada.

There are many other reasons to feel optimistic - very recent opinion polls indicate that there continues to be a lot of public support for renewable energy. To impress upon our new Minister this reality, we are getting him a table-sized model of a wind turbine for his office and I take this as a positive sign. We had better be sure that we supply him with a good machine.

Another encouraging sign is the level of interest being shown in this field by utilities and also private investors. Over the past several months we have been approached by some utility representatives who are very seriously exploring the possibility of installing wind machines in their grid systems. In addition to this some private investors have contacted us lately with the idea of privately financing wind energy farms. Furthermore, we have seen a lot of interest in wind coming from some of our remote communities, particularly up north. There are markets emerging in Canada and this means business opportunities for wind energy companies.

There are a number of other successes that we've seen over the last year. The Class 34 Accelerated Depreciation Allowance was amended by our Finance department to include wind energy machines that produce electricity. The Atlantic Wind Test Site responsibility was transferred from NRC to EMR and now we have taken steps to include private companies in the management board. Another sign is evident from our joint Federal/Provincial agreements or Memoranda of Understanding, where several provinces have indicated strong support for wind energy projects as part of these agreements. Quebec in particular, has taken this position.

Une autre réalisation d'importance qui permettra à l'énergie éolienne d'être plus visible est le Projet ÉOLE.

ÉOLE:

Le projet ÉOLE, la plus grande éolienne à axe verticale au monde sera finalement complété d'ici la fin de l'année 1986. Ce projet maintenant la propriété du groupe Conseil Lavalin, est une autre preuve du savoir-faire canadien. Quoi que le marché pour les éoliennes de l'ordre du mégawatt soit présentement incertain, une quantité d'information substantielle sera créé grâce à la réalisation et à l'opération d'ÉOLE. Et si on parle du marché, il est intéressant de savoir qu'il y a quelques nouveaux pays qui décidé de se lancer dans le développement des éoliennes de l'ordre du mégawatt. L'Espagne, l'Italie, et même la Russie ont des projets d'éoliennes de plusieurs mégawatts.

What I've described might be said to represent the bright side of the coin. There are still many roadblocks ahead. For one thing I know many people complain about the lack of a "level playing field" between our various energy technologies. Things like hidden subsidies and the seemingly impossible task of establishing true fuel costs at the margin are often brought up in such arguments.

While I do not want to comment on the justification of these remarks I can tell you that we are making direct efforts to answer the many questions we all have about these points. For example, we are embarking on a study of this level playing field issue and we expect to have results within a few months. I know Jeff Passmore is one man who would love to get his hands on this information and I can promise that he will be one of the first to get it.

Another difficult question here for us all is what role should be played by the utilities in wind technology.

It's good to see that several Canadian utilities are represented here today. I take that as a positive sign and I hope we will see this co-operation and interest grow as the technology continues to improve. We have some very exciting demonstrations being planned that should be of interest to the utilities.

On the subject of demonstrations there is another issue here which I would like to bring up. The remote community demonstrations which are being planned will likely require machines in the power range of 15 to 60 kW. Now as most of you are aware we really do not have good, reliable Canadian machine in this range at a reasonable price. This certainly creates a problem for us at EMR since we obviously want to buy Canadian if we can but we must, on the other hand, try to make these installation as cost-effective as possible. I don't really have an answer to this problem since the whole matter of the optimum size for a wind machine has not been resolved. I do, however, want to make you aware of this situation and I welcome any advice and comments you might have to give us.

I would like to briefly touch on the Federal programs for wind and also outline the future, at least as I see it, over the next few years. As you know the federal government is looking for ways to reduce its deficit and these are uncertain times for virtually all government programs. While the Research and Development programs appear to be solidly in place into 1990, the future of the demonstration programs is not so clear. The National Conservation and Alternative Energy Initiative or NCAEI is the funding source for most of our renewable energy programs and it is due to expire in March 1988.

We are presently consulting industry and the provinces/territories as to what we should do post-NCAEI. A meeting with CREIC is scheduled for November 24 to discuss this issue with our Minister.

As mentioned earlier, we are initiating a study to determine the level playing field between the different energy resources in Canada. I believe this will help us to better state our case and to better establish our priorities for each technology.

There are several demonstration projects, either underway or at the final planning stage and we intend to spend over one million dollars of EMR money on these projects. These will be discussed in more detail later on in the conference program but I certainly count these as important steps towards further commercializing this technology. Recognizing this, EMR will be placing a high priority on this work to ensure that the results are successful.

On the subject of what the government is doing in this area I would like to draw attention to another significant contribution being made by the Federal Government through the person of Monique Carpentier. I think you are getting the services of one of our government's finest people by having Monique as the Technology Coordinator in this area and I hope you appreciate it. Speaking for my Branch I can certainly state that we do.

Well that concludes my remarks. My message is meant to be encouraging. I believe we've taken some very long steps towards commercializing this technology thanks to the efforts of those of you in the room today. I have mentioned the hurdles that are still there. None of these are insurmountable. The key is a solid spirit of co-operation between governments, utilities and industry. That's what this conference is all about.

Mesdames et Messieurs, je vous remercie de votre attention. Je suis très heureux d'avoir eu la chance de vous parler et je vous souhaite une bonne conférence. J'assisterai à vos présentations et j'espère avoir l'occasion de vous parler individuellement durant ces prochains deux jours.

TECHNICAL PAPERS

THE COMMERCIAL MARKET

COMMERCIAL MARKETPLACE IN ALBERTA

By: Dale Johnson

In addressing the "Commercial Marketplace In Alberta", I would like to present a broad overview of the situation in the province which will include the following areas:

1. Wind Power Inc. - History.
2. Small Power Producers Association of Alberta - objectives and accomplishments.
3. Political Climate - Government, Public Utilities Board and the Energy Resources Conservation Board.
4. Market Atmosphere - Purchasers of wind energy conversion systems.
5. Slide Presentation - Agricultural and commercial installations.

WIND POWER INC.

Over the past four years, Wind Power Inc. has evolved from a sales and marketing organization to include installation and service of wind energy conversion systems (WECS). With 3 installations presently underway in Alberta, we now have been responsible for the sale and/or installation of 10 of the 13 grid interconnected WECS in the province. We have been active in negotiations with the utility companies, the Energy Resources Conservation Board (ERCB), and the Public Utilities Board (PUB) as well as lobbying efforts with the Provincial Government. Additionally, we have become familiar with the requirements of the Alberta Electrical Protection Branch and other provincial policies and procedures. Wind Power Inc. has also been instrumental in the development of the "Fort Macleod Wind Farm", the first commercial wind park in Canada.

SMALL POWER PRODUCERS ASSOCIATION OF ALBERTA

In the spring of 1985, the Small Power Producers Association of Alberta (SPPAA) was formed in Claresholm, Alberta. One of the main objectives of the Association is: To represent the interests of the renewable energy industry to municipal, provincial and federal governments in Canada and to, thereby, encourage the adoption of equitable legislative and economic conditions for the industry. This has been the thrust of the Association for the past 18 months.

The SPPAA has joined other similar organizations nationally and internationally, including the Conservation/Renewable Energy Industry Council and, most recently, co-sponsored the Great Plains Wind Energy Conference in Minnesota.

After months of negotiations with the utility company and meetings with the Electric Utility Planning Council (EUPC), little progress has been made. In dealing with a large monopolistic body, such as the utility company, it is easy to understand the lack of concern and discouraging attitudes associated with the diversification and ultimate competition in the electrical generating marketplace. The basic attitude is, if you don't like what we have to offer, you can always go the the ERCB, PUB or the government.

SMALL POWER PRODUCERS ASSOCATION OF ALBERTA (Cont'd.)

In a recent hearing, Alberta Power Ltd (in a revised electric service regulation) put forth pricing of customer generated electricity which bears little resemblance to the way TransAlta Utilities seems to derive prices for the same type of generation. As the utility companies cannot even agree with one another, the Association would like to have one public hearing to determine pricing, standard offer contracts and an allotment of power dedicated to small power producers, etc. All renewable resources would be heard at one forum.

The Association is made up of dedicated, persevering individuals who have the support of thousands of Albertans and will, therefore, see positive solutions to the problems facing the small power industry in the province. On a positive note, the Small Power Producers Association, together with TransAlta Utilities, have recently negotiated "annual banking" - a concept of crediting winter surplus generation against excess summer consumption; a policy which the ERCB has now approved.

POLITICAL CLIMATE

It is interesting to note the government's unwillingness to resolve the small power producer's issue because "it is so very complicated and has such far reaching implications". There appears, however, to be no problem in proceeding with a 1.6 billion dollar coal fired plant, the only rationale for which seems to be to create jobs. The small power industry could also create jobs with 1.6 billion dollars (as well as diversify the economy, create a new industry and, at the same time, secure the future of the ratepayer so there would be no more billion dollar mistakes made related to long range mega-project planning).

The government would have small power producers deal with the ERCB, PUB and/or the utility companies thereby avoiding the issues. It is ironic that, in meeting with the PUB and ERCB, their representatives insist that the system will work for small power producers as it does for large utility companies, however at the same time, suggest that legislation or amendments to present regulations would be the answer to solving small power producer's problems. "Catch 22" - new legislation (or amendments) have been the very objectives of the SPPAA since it's inception.

The fact is, there is room for and a need for smaller electricity producing facilities in the marketplace. It seems more and more obvious that in order to create a niche for small power production, government intervention at some level will be needed to ensure the industry a solid jumping off point.

MARKET ATMOSPHERE

When discussing electrical issues with people in Alberta, the old adage "competition is good for the consumer" is evident. There is a certain animosity toward the utility companies because of the monopoly situation coupled with the guaranteed rate of return based upon revenue requirements as opposed to a market oriented value for the commodity.

Albertans are more aware than ever that the time has arrived to; diversify our generation base, conserve our non-renewable resources and produce pollution-free energy. Costs per kilowatt for small power facilities has declined rapidly and, in many cases, is now less than utility installed capacity. There is no doubt that lower cost generation coming on the system will eventually tend to stabilize and levelize ever increasing rates.

With the exception of the Lethbridge Wind Test Site (which tests water pumping windmills), there is basically no research and development in the province. There is a monitoring program in place for electric machines as a result of the Sinnott Hearing before the ERCB in 1984, however, monitoring and data gathering is being done on WECS which have been sold commercially.

A cross section of purchasers in the province shows that a growing and maturing of the industry is taking place. Initially, some small units were installed on acreages. Next farm and ranch installations began to happen. Media attention started to grow and articles began to appear in local and regional papers. The provincial Minister of the Environment attended the official dedication of the Sinnott machine at Pincher Creek.

The Spring of this year saw the Cardson School Division purchase 2 Enertechs, model E44/60 and Leth's Turkey Farm at Taber purchased the largest WECS on the Alberta grid, a Nordtank NTK 65/13. Commissioning of these projects was in August and September. These units attracted national media attention and brought CBC Country Canada from Winnipeg to film the installation of the Nordtank at Taber.

Three more Nordtank's have been sold in the past 8 weeks. One unit is an agricultural application, the other two - commerical. The two commercial WECS will be producing power for a senior citizens lodge and a restaurant. Both of these units are to be located at Fort Macleod where the most recent and progressive wind power development has taken place. The Town of Fort Macleod (owners of their own distriubition system) have designated a piece of town property for a wind farm. Residents may invest in a wind machine, install it on the designated property and debit electrical consumption from machine production. The same "banking" concept has been adopted as was proposed in the 1984 Sinnott Hearing (see Reference #1). Fort Macleod is excited about the new concept and, being corporate members of the Small Power Producers Association of Alberta, were enthusiastic in breaking new ground and setting a precedent in Canada. As the first commerical wind farm in Canada, the Town will undertake promotion through the local Chamber of Commerce, tourist information packages, etc. The people of Fort Macleod take pride in their rich heritage as one of the first outposts in western Canada and have once again demonstrated that competent and progressive spirit which re-establishes them as a pioneer town - past, present and future.

In conclusion, with recent direction from the Albert government to both the ERCB and PUB on a possible joint Hearing, small power producers are anxiously awaiting the next step.

As the small power renewable energy attitude begins to take hold in Alberta, progress is being made in spite of the same negative factors which have plagued small power producers world-wide. Until such time as there are policies and prices in place to accomodate wind farmers, in the traditional sense, my opinion is that the marketplace in the province will tend to be driven more and more by activity in the commercial and industrial sectors.

To date, in Canada, Alberta has been the leader in commercial sales of wind energy conversion systems. With the Ernie Sinnotts of the world and towns like Fort Macleod with their positive progressive attitudes as accompanying forces, Alberta will undoubtedly remain in the forefront of the wind industry in Canada.

Reference # 1

ENERGY RESOURCES CONSERVATION BOARD

Calgary Alberta

WIND-POWERED ELECTRIC GENERATOR OF A. E. SINNOTT NEAR PINCHER CREEK

Decision D 84-12
Application 840007

1 INTRODUCTION

1.1 The Application

A. E. Sinnott applied, pursuant to sections 14 and 15 of the Hydro and Electric Energy Regulation, for approval to operate a wind-powered electric generator of about 40-kilowatt (kW) capacity, and pursuant to sections 17(2)(a) and (b) of the Hydro and Electric Energy Act, for approval to connect the generator to the eletric distribution system of TransAlta Utilities Corporation (TransAlta). The generator is located on his land in the northwest quarter, section 2, township 7, range 30, west of the 4th meridian. He requested that the Board address matters relating to the allocation of costs and other terms and conditions associated with the interconnection.

1.2 The Hearing

The application was considered at a public hearing in Lethbridge, Alberta, on 20 and 21 March 1984, with C. J. Goodman, P.Eng., F. J. Mink, P.Eng., and R. G. Paterson, P.Eng., sitting. Those who appeared at the hearing are listed in the attached table.

1.3 Background

Mr. Sinnott and his family own and operate a 650-hectare farm near the town of Pincher Creek. The operation includes three residences, grain-handling facilities, an anhydrous ammonia fertilizer sales facility, a shop, and other farm facilities. The farm was originally served by a single-phase 230-volt, 25-kilovolt-ampere supply from rural distribution lines. Planned expansion of the overall farming operation requires an electric power supply in excess of the maximum capacity of the single-phase line. A 3-phase power supply has recently been installed by TransAlta at the Sinnott farm.

In view of his expected long-term growth in electric energy requirement, Mr. Sinnott also investigated and decided to purchase a 40-kW wind-powered generator that would meet all his present and future requirements. His present need, however, is significantly below the expected capability of the machine. Mr. Sinnott applied for and received interim approval from the Board to operate his generator and to connect it with TransAlta's system. TransAlta is prepared to purchase all the surplus energy available from his generator.

Mr. Sinnott and TransAlta were unable to agree on a price for his surplus energy, as well as other matters such as sharing of the interconnection and metering costs, and insurance and liability. The application was filed with the Board for resolution of these matters as well as to receive final approval for the operation of the generator and the interconnection with TransAlta's system.

2 APPLICANT'S SUBMISSION

2.1 The Proposed Plant and Interconnection

The applicant stated that, based on recent records, his present electric energy consumption averages about 2000 kilowatt-hours (kWh) per month throughout the year. This is expected to increase to about 6000 kWh per month over the next few years as farming and fertilizer operations are expanded. The maximum monthly consumption may approach 10 000 kWh per month if electric heating is also utilized, but this option depends to a degree on the price that would be paid for surplus energy delivered to TransAlta.

Mr. Sinnott has installed an Enertech Model 44/40, 3-phase 460-volt wind-powered generator, rated at 45 kW at a wind speed of 80 kilometres per hour. He estimated the average annual energy output of his generator to be between 120 000 kWh and 140 000 kWh based on recorded meteorological data at the Lethbridge station. The wind-powered generator has been connected to the local 3-phase distribution system of TransAlta to provide induction power to energize the generator, supply back-up power for Mr. Sinnott's operation during periods when demand exceeds generation or if the generator is not operating, and to facilitate sale of surplus energy to TransAlta.

The applicant stated that his generating facility is constructed and is operating in accordance with Canadian Standards Association standards and Electrical Protection Branch regulations. Voltage and frequency are within generally accepted utility limits. In addition, over- and under-voltage and frequency controls are installed. A disconnect switch is installed to allow the generator to be isolated from TransAlta's distribution system to assure safety of linemen working on the system downstream from the generator.

2.2 Public Interest Effects

The applicant stated that he was prepared to absorb the capital cost of approximately $90 000 for the wind-powered generator. He submitted that he should in turn receive fair value for the surplus energy delivered to TransAlta. He contended that interconnection of his installation would defer construction of new generating facilities on the Alberta interconnected electric system (AIS), even though only by a small amount compared to the size of the generating units presently being added to the AIS. During periods of surplus energy sales to TransAlta, there would be savings in fuel, operating, and other associated costs to the utilities. Because the wind-powered generator is located close to other distribution loads, transmission and distribution losses would be reduced. Therefore, customers of the AIS would benefit from his installation and, since he has paid the full capital cost for the generator, no one else would be adversely affected.

The applicant stated that, because wind energy is a renewable resource and pollution free, wind-power installations should be encouraged in southern Alberta where there is a high wind regime, particularly in the winter chinook months when the system power demand is also highest. The applicant also expressed the opinion that wind-powered generators should be installed on the basis of their own economic merits, and the price paid for surplus wind energy should not be subsidized by customers of the AIS.

2.3 Sale of Surplus Energy

The applicant stated that, in the first few years, his wind-powered generator would generate more energy annually than his operations required. TransAlta has agreed to interconnect the generator and has offered to purchase any surplus energy generated. TransAlta's offer is based on installing two separate uni-directional meters for the interconnection, one to measure flow to Mr. Sinnott's operation and to be charged at normal utility rates, the other to measure surplus energy flow to TransAlta's system that would be paid for at the price of 1.6¢/kWh, but subject to any further order of the Public Utilities Board. The applicant argued that TransAlta's proposal to purchase surplus energy is unfair because it does not recognize the contribution made by the generator to reduce the need for new capacity on the AIS, and the rate of 1.6¢/kWh offered for his surplus energy is far below its true value.

The applicant proposed two options for the exchange of electricity between him and TransAlta. The first option, which he referred to as "net energy billing", is a sharing of energy and capacity, recognizing the economics to both parties involved. The net excess electric capacity and energy at the end of a billing period would be delivered free of charge to TransAlta who would resell it elsewhere at full retail value. In return, TransAlta would supply any shortfall in his energy requirements during periods of low or no wind generation. In this arrangement, energy would be measured by allowing the standard meter to run in reverse when surplus energy is being produced. The net energy supplied by TransAlta would be charged at normal utility rates.

The second option suggested was the 'surplus energy purchase' option under which all the energy supplied by TransAlta would be metered and billed at normal utility rates. The energy supplied by the applicant to TransAlta would be metered separately and paid for at a rate equivalent to the highest-cost energy produced on the TransAlta system. This option assumes that the most expensive energy produced by TransAlta (or AIS) would be cut back first during periods when the wind-powered generator is producing excess energy. Determination of highest-cost energy would take into account the displacement fuel and long-term avoided costs associated with that generation. This would require installation of two uni-directional meters wired in series.

2.4 Other Terms and Conditions

The applicant claimed that interconnection and metering costs should be shared between TransAlta and himself, since the wind plant provides some benefits to the customers of TransAlta. Mr. Sinnott was also concerned that the level of third-party insurance that TransAlta insisted he carry is excessive, given the risk associated with the interconnection.

3 INTERVENERS' SUBMISSIONS

D. M. Cousins supported the application. Using Pincher Creek wind data, he calculated a slightly lower average annual output of 112 500 kWh for the wind-powered generator. He stated that at the time of year when the demand on the AIS is at its highest level, the power available from the wind is also at its highest level. Because of the very nature of the wind, the AIS must react very quickly to compensate for fluctuating production from the generators. In his opinion, this reaction would likely be a reduction in water flow to a hydro-generating unit, resulting in storage of that water in the reservoir for use at a later time. Mr. Cousins also stated that the small power producer (SPP) should not be subsidized by the utility or its customers, but sufficient wind-powered generators should be built so that they could be studied and more data gathered about their operation.

R. M. Bennett was in favour of the application. He stated that a higher rate should be paid for sales of any surplus energy and that the net energy billing option should be available to an SPP. Mr. Bennett also argued that TransAlta's requirement for the applicant to carry $2 million of third-party liability insurance was excessive. He noted that farm customers who operate standby generators in conjunction with their normal supply from the AIS are not required to carry insurance even though they pose similar risks as the Sinnott installation.

W. Arsene supported the application on the basis that there are employment and economic benefits associated with the wind-energy industry. He favoured a trial period to gain more information regarding wind-powered generator operation and associated costs.

J. Edworthy of Nor'wester Energy Systems Ltd. (Nor'wester Energy) estimated the annual energy production from the wind-powered generator would be about 115 000 kWh. He outlined several benefits of wind power, such as deferment of capital expenditures by the utilities, increased reliability of the system due to generation dispersion, economic benefits, job opportunities, energy diversity, conservation of fossil resources, and protection of the environment. He was of the opinion that the applicant should bear the interconnection and metering costs. He argued that rates set for sale of excess energy to TransAlta should include consideration for avoided line losses (because generation is located near the load), generating capacity credit, avoided fuel costs, and some recognition of the costs of the generation by the SPP. He agreed that the utility and the SPP should not subsidize each other.

Considering that limited information is available on the effects of wind power in Alberta, Mr. Edworthy recommended that the Board adopt an interim policy for the next three years to encourage development of wind power to a maximum total capacity of 100 megawatts. After that time, all relevant issues and policies should be reviewed based on local practical operating experience. He further recommended that, in conjunction with this interim period, a joint committee be established of utility, government, wind-energy industry, and citizen members to monitor wind-powered generator and utility interactions, performance, and concerns raised by the issues discussed at the hearing. This committee would be charged with arriving at recommendations regarding allocation of costs, liability, and other concerns based on operating experience in Alberta and reporting these recommendations to the Board for policy revisions.

Alberta Power Limited (Alberta Power) stated that utility interconnections with customer-owned generation should be encouraged to promote the efficient use of energy resources and the innovative and economic development of conventional and alternative electric energy sources. It argued that all consumers of electricity should benefit from customer-owned generation interconnected with a utility's system. Also, customer-owned generation should be considered as a customer class of negative load with credits for demand (capacity) and energy based on the reduction of system co-incident peak load and savings in energy generation. Alberta Power suggested that surplus energy from an SPP be bought at a fixed rate which would be somewhat less than what Alberta Power sells its energy for, but one which would make some allowance for capacity credit.

TransAlta supported the principle of customer-owned generation and took the position that any customer may interconnect and operate electrical generation in parallel with TransAlta's system. In order to be fair to the rest of its customers, TransAlta said it is prepared to purchase all of Mr. Sinnott's surplus energy at a price equivalent to avoided AIS energy cost.

TransAlta submitted that it would be more appropriate to use wind data gathered at the Pincher Creek station to compute average annual energy production from Mr. Sinnott's generator, and it estimated this would amount to about 100 000 kWh.

TransAlta noted that the wind-powered generator must be interconnected with an external source of power in order to start and operate it, and that it would shut down if there is a loss of power from the external source. It also noted that the output from the proposed generator is primarily dedicated to supply the applicant's own requirements. Energy would not be available to TransAlta unless it is not required by Mr. Sinnott's own operations. As there is no assurance of supply of any amount to TransAlta at any given time, there could be no capacity costs avoided by TransAlta. Therefore, the value of Mr. Sinnott's surplus energy to TransAlta lies in displacement of AIS energy only, and in a small reduction in transmission losses. In calculating the value of Mr. Sinnott's surplus energy, TransAlta estimated that the generator energy production would be distributed equally over the year, and the net fuel savings would consist of 50 per cent gas and 50 per cent coal. Allowing an additional 5 per cent credit for savings in line losses at the transmission level, TransAlta determined that 1.6¢/kWh would be appropriate for the avoided energy cost. Allowance for savings in line losses at the distribution level should not be included because any potential savings are offset by the need to distribute the surplus energy purchased over the distribution system. TransAlta stated that, if the applicant is prepared to dedicate his capacity to the system, there may well then be some credit for capacity.

TransAlta stated that interconnection and metering costs should be entirely absorbed by the applicant unless the benefits of the wind-powered generator are also shared. TransAlta said it would install, at its own cost, a time-of-day meter on an experimental basis at Mr. Sinnott's facility to assess the capacity the generator can actually provide each hour of the day, and to monitor the characteristics of the generator.

4 BOARD'S VIEWS

This report deals with the specific issues of the application. The applicant also submitted a significant amount of information and related material regarding wind-power production in other jurisdictions. Much of this material is not discussed in this report and may not be applicable to Alberta, but might provide useful information to interested persons.

Since the present application may be the first of many similar applications by SPPs, the Board has dealt specifically with the application in the body of this report and then expanded upon its views, or dealt with other matters, in the appendix. Although each future application would be decided upon its particular merits and facts, some general principles applied by the Board in dealing with this application are discussed in the appendix.

The Board observes that the proposed wind-powered generator is equipped with voltage and frequency protection relays and notes that it meets TransAlta's requirements for parallel operation with the utility system. Furthermore, Mr. Sinnott stated that the generator would comply with standards as set out by the Canadian Standards Association and the Electrical Protection Branch. The safety of linemen working on a line connected to an SPP facility is a valid concern, and the SPP operator must take sufficient precautions. In this respect, the Board is satisfied that Mr. Sinnott and TransAlta will install the necessary equipment required to prevent unsafe occurrences.

A range of estimates of the output of the Sinnott installation was presented and discussed, and the Board believes it would probably be more accurate to use the wind data from the closest meteorological station to the wind-powered generator to compute the annual energy production and the likely economic benefit of the facility to him. In this instance, the differences are small and the overall analysis pertinent to the decision is not materially affected.

On the relationship and effect of Mr. Sinnott's generator on the TransAlta and Alberta systems, as discussed more fully in the appendix, the Board believes that while the effects may be real the impact of a single SPP cannot, at this time, be accurately determined. The relationship and effect of SPPs on the AIS will depend upon the development of SPPs and will require analysis of their operating experience. To this end, the Board believes a concerted effort should be made to obtain credible technical information on the operation and interaction of the generator with TransAlta's system.

The Board does acknowledge some of the potential benefits of SPPs as presented by the Sinnott application. The Board also believes that a desirable environment for the development of SPPs should be encouraged and, in its opinion, a period of experience to gather information on the performance of SPPs is necessary to reconcile their true impact on the AIS.

The Board notes that the wind-powered generator would be used to meet Mr. Sinnott's own requirement first, and only surplus energy would be made available to TransAlta. Furthermore, Mr. Sinnott needs an interconnection with the distribution system of TransAlta for generator induction power, back-up supply, and to feed surplus energy back to the utility. So in a sense, Mr. Sinnott would continue to be a customer and a load to TransAlta and would be billed at the same rate as other customers with similar loads. To the extent that Mr. Sinnott reduces his own load, the Board believes that this will, on average, reduce TransAlta's generation and tend to delay new generation capacity requirements, even though by a very minute amount. Therefore, TransAlta will see an actual reduction in energy generated since Mr. Sinnott will take less energy from TransAlta than he would have as a pure load, ie with no generator. For these very general and simplistic reasons, the Board believes that, for a trial or learning period, very simple cost procedures should be used for arriving at the value of surplus energy from the applicant's plant. Also, the applicant should then be content to receive some but not all of the perceived, and yet unproven, benefits of his generator.

The Board believes that Mr. Sinnott's operation should be treated as that of a customer who, by managing his load to conserve energy, will reduce his requirements from TransAlta. Furthermore, Mr. Sinnott should be compensated for the surplus energy that he generates by being allowed to "bank" it in TransAlta's system during periods when his generation exceeds his load. Mr. Sinnott would then be able to use his "banked" energy during periods of low or zero generation by drawing energy from the TransAlta system. Although this is similar to the net energy billing concept suggested by the applicant, the Board believes that, during the learning period, two meters should be installed. One meter would record all the energy production from the wind-powered generator and the other would record Mr. Sinnott's consumption, and the difference in the two meter readings would be used to compute the billing. The Board would suggest that the banking and the billing period should be identical and that a quarterly billing period would appear suitable. If during each such period TransAlta is a net supplier of energy to the applicant, then he would be billed for this energy at the usual utility rates, but if the applicant produces more energy than his own requirement during the same period, then TransAlta would compensate him for such surplus energy at a suitable surplus energy rate.

The Board believes there is some definite but unquantifiable capacity contribution made by Mr. Sinnott's wind-powered generator, and that this would be compensated for by the reduction in energy cost to Mr. Sinnott by the modified net energy billing concept which would allow him to bank excess energy in TransAlta's system for his later use.

The Board believes that any cost to TransAlta of foregoing the charge for the energy Mr. Sinnott produces for himself is a reasonable cost for the trial period with this form of energy production. However, TransAlta should recover the cost of kilowatt demand capacity required by the applicant's operation and provided by TransAlta, just as it would for any other load with a similar service. If the present rate structure does not adequately cover the cost of providing required kilowatt demand capacity, an appeal could be made to the Public Utilities Board to set an appropriate rate.

Respecting the value of surplus energy, TransAlta computed an avoided energy cost derived on the basis of displacement of 50 per cent gas-fired energy and 50 per cent coal-fired energy, plus 5 per cent credit for avoiding line losses at the transmission level. The Board believes that during the trial period this is a fair method for computing costs avoided by TransAlta as a result of net surplus energy delivered to it from the interconnection with the applicant's facilities. The Board believes this interim arrangement would be fair to both parties and would be without substantial subsidy. However, this should be reviewed and adjusted as the cost of service is revised by the Public Utilities Board from time to time.

As stated earlier, the Board believes there should be a trial or learning period to determine the true impact of the Sinnott installation. During this period, TransAlta should, with the co-operation of the applicant, obtain all relevant technical and cost information on the operation and interaction of the Sinnott wind-powered generator with the TransAlta system, and submit to the Board a report on this matter for each calendar year and a final summary report before the end of the trial period. Should the Electric Utility Planning Council choose to submit a report or describe an industry position, the Board would welcome it. This trial or learning period should be for five years ending 31 December 1989.

The Board believes that all costs incurred by TransAlta that are beyond those required to connect and meter a customer of similar service size and class, should be paid for by the applicant. The costs of special test metering during the trial period should be borne by TransAlta, and the Board was encouraged to hear TransAlta's plans to install a time-of-day meter, at its own cost, for experimental purposes. In addition, all costs incurred by the applicant to allow for the safe and reliable operation of its generation in parallel with TransAlta's system should be borne by the applicant. If further interpretation is required, the Board observes that all parties agreed that neither an SPP nor a utility should subsidize each other.

The Board assumes that TransAlta would treat customers with standby generation, or with a generator such as Mr. Sinnott's, equally; however, the Board considers matters such as liability or insurance to be part of normal business arrangements and should be resolved by negotiation between Mr. Sinnott and TransAlta.

5 DECISION

Having considered the evidence, the Board believes that the construction, operation, and interconnection of the Sinnott wind-powered generating facility is in the public interest and consistent with the requirements of the Hydro and Electric Energy Act.

The Board is prepared to issue a final approval for the operation of the wind-powered generator, and an order to allow the continued inter-connection of the wind-powered generator to the distribution system of TransAlta Utilities Corporation.

DATED at Calgary, Alberta, on 8 June 1984.

ENERGY RESOURCES CONSERVATION BOARD

C. J. Goodman

C. J. Goodman, P.Eng.
Board Member

F. J. Mink, P.Eng.
Acting Board Member

R. G. Paterson

R. G. Paterson, P.Eng.
Acting Board Member

THOSE WHO APPEARED AT THE HEARING

Principals and Representatives (Abbreviations used in Report)	Witnesses
A. E. Sinnott G. Jasman	A. E. Sinnott D. Gilmer of Enertech Corporation J. Otis of Wind Dynamics D. Johnson of Wind Dynamics
TransAlta Utilities Corporation (TransAlta) M. H. Patterson, Q.C. E. J. McCoy	G. D. Lyons, P.Eng. M. J. Chorel, P.Eng.
Alberta Power Limited (Alberta Power) K. F. Miller	C. O. Twa, P.Eng. B. Laing, P.Eng. R. V. Baer, P.Eng.
Nor'wester Energy Systems Ltd. (Nor'wester Energy) J. Edworthy	J. Edworthy
R. M. Bennett	R. M. Bennett
W. Arsene	W. Arsene
D. M. Cousins, P.Eng.	D. M. Cousins, P.Eng.
Energy Resources Conservation Board staff M. J. Bruni A. Kwaczek F. Rahnama J.N.G. Yu, P.Eng. S. S. Lota, P.Eng.	

APPENDIX
TO DECISION D 84-12 ON THE SINNOT WIND-POWERED GENERATOR

Given the growing interest in small power production and co-generation in Alberta, the Board believes it is appropriate to expand and illustrate its views developed in reaching a decision on the Sinnot application for approval of the operation of a wind-powered generator connected to the Alberta interconnected electric system (AIS). Following this first hearing dealing with the interconnection of a small power production facility and the AIS, the Board concluded that, while the potential benefits and impacts of small power production could be described, the lack of operating experience precluded an adequate assessment of these factors. Considering the interest in the Sinnott application, the Board anticipates this may well be the first of many similar applications.

For purposes of this report, the Board defines a small power producer (SPP) as a connected utility customer that supplies some or all of its own electric load from its own on-site generation of 100 kilowatts or less of total installed name-plate capacity. This is distinct from co-generation, which usually involves the generation of electricity with thermal energy required for some other purpose. Such co-generation is often associated with large industrial projects and is negotiated as part of a supply contract with the appropriate electric utility. Furthermore, most co-generation projects to date have involved generating capacities much larger than those associated with SPPs.

Benefits to Alberta

The Board recognizes that favourable wind regimes occur in much of Alberta, creating considerable potential for development of wind-powered electric generation. The development of wind-powered electric generation, and the possibility of other forms of small power production which would utilize renewable resources, would be desirable even at a modest scale as environmentally sound energy sources that would conserve non-renewable resources. The economics largely remain to be tested and proven. The development of small power production facilities could conceivably provide a unique opportunity for modest economic benefits to Alberta's agricultural industry as well as job opportunities in the design, manufacture, and installation of such facilities. It is apparent that the technology in this area has made considerable progress in recent years. The Board accepts that the technology exists to make the small power production both safe and compatible with the AIS.

In light of the potential benefits, and considering the need for information on the operation of SPP facilities appropriate to the Alberta energy scene, the Board believes that a suitable environment for development of small power production facilities is advisable for a trial period.

Interaction of SPP Facilities and Utility Systems

In considering the suitability of SPP facility development, it is necessary to consider their interaction with a large electric utility system and the AIS. The Board observes that major impacts such as the addition of a power plant, a large industrial consumer, or even an industrial co-generator can be measured and predicted with some degree of accuracy. When it comes to an SPP, the effects are small and measured in minute increments of utility operations. The Board concludes that although the effect may indeed be real, the arguments as to their nature tend to be hypothetical simply because any measure of an impact is lost in the myriad of other small loads on the system. The major issue surrounding the development of small power production usually revolves around the benefits such facilities provide to the AIS, and accordingly, what the price of surplus energy delivered to the AIS should be. The Board believes that one approach to resolving this problem exists in the statistical methods used by the utilities to plan for the numerous small loads scattered throughout the system. While no individual small load causes a utility to add a generator, the cumulative growth can be estimated within certain confidence limits, and it is this aggregate of small loads which ultimately creates the need for additional generators. The degree of confidence depends on both the large number of small loads and the utilities' experience in planning for and servicing small loads.

Similar experience does not exist for SPPs, however, the Board believes the methodology would be appropriate and should be more useful than the essentially hypothetical arguments. Although these arguments cannot be discarded entirely, only operating experience with SPP facilities will provide any resolution. A concerted effort should therefore be made to obtain valid information on the operation and interaction of SPPs with the AIS. The Board believes that the installation and operation of special instrumentation for such purposes, ie other than standard meters for billing, should be the responsibility of the utility. This detailed information on the performance of an SPP facility is fundamental to determining the relationship to the utility in respect to peaking coincidence, capacity, and potential for some degree of dedication of capacity. The utilities have the expertise for such an evaluation at the common interface with SPPs and are also able to observe the overall impact of SPPs on the system.

Economic Considerations

For any individual SPP to provide the quality of service available from a utility would require several generators, spinning reserve, and perhaps even energy storage at the SPP facility site. It is very unlikely that this would be cost competitive with large-scale utility generation.

In fact, economic analysis similar to that which a utility would use to evaluate a new generating source would indicate that small power production facilities are probably not as economic as utility service. However, the SPP utilizing a renewable resource to supply part or all of its own load, and generating some surplus for sale to a utility, may be in a better position from its own viewpoint. In the case of a farm operator, there is apparently the satisfaction of self-sufficiency and the knowledge of predetermined electric energy costs. In some cases, the SPP might have tax advantages that would make the installation economically attractive to the operator even though unattractive under utility financing.

While the Board is concerned about conservation of any energy resource, it cannot ignore economic and efficient recovery of it anymore than it can ignore economic and orderly development of the AIS. At the hearing of the Sinnott application there was a consensus that neither SPPs nor the utilities and their customers should subsidize one another. In developments to date, initiative has been shown by the few SPPs and there has been co-operation by the utilities to conserve the energy produced.

Interim Policy

As noted before, the Board does not believe it is possible at this time to calculate in great detail the effects, and hence the costs and benefits, of an SPP facility. Instead, the following is presented as a basis for a suitable compromise between the interests of the SPP and utilities for an interim trial and learning period.

The Board expects that small SPPs will request interconnection with the utility for technical reasons, back-up supply, and to feed surplus energy back to the utility. So in a real sense the SPP continues to be a customer and a load to the utility, and the net energy in kilowatt hours (kWh) and the peak load demand in kilowatts supplied by the utility would be billed at a similar rate as for other customers with similar loads.

To the extent that the SPP reduces its own load on an annual and peak time basis, it will on average reduce utility generation and tend to delay new generators, thereby reducing AIS cost. Conversely, if it takes little net energy but continues to take full power demand at time of system peak, it will not delay additional generation and, again on average, could tend to reduce the AIS load factor and thereby slightly increase generating costs.

Turning to energy fed back into the AIS and theoretically distributed to nearby utility customers, the Board expects that the only effect on the utility will be a nearly negligible reduction in the actual on-line AIS generation.[1] Whatever surplus energy the SPP produces would be absorbed by other customers of the utility at that moment and paid for by them at a fixed rate, and for its customers other than the SPP the utility sees no change. The utility will continue to recover its revenue from all other customers as though there were no effect from the SPP. The only "change" seen by the utility, if it is really a change, is that the SPP has on average taken less kWh from the system than it would have as a pure load. Admittedly, the utilities would have some increased administrative costs due to SPPs.

For these very general and admittedly simplistic reasons, the Board believes that very simple cost-recovery procedures should be applied during a trial or learning period during which the impact of SPPs should be studied. During this trial period, the Board expects there will be few SPPs and their effect on the AIS will be minimal. If the simple cost procedures as proposed are in error, then in the interim the error should probably be absorbed by the much larger utilities and the many customers of the AIS in the interest of conservation. The SPPs should in turn be content to receive some but not all of the perceived but not proven benefits of their pioneering.

The simple procedures that the Board believes should be applied during the trial period would regard an SPP as a load on the AIS. As with any customer load that is managed by the customer to conserve energy, that load will probably be less than it would have been without such management. Application of what has been termed "net energy billing", in which one meter records supply to an SPP and another the energy flowing to the system from the SPP should present no great hardship to the utility but would provide a substantial advantage to the SPP that is able to "bank" its energy with the utility and withdraw it as needed.

Very simply, for the trial period, an SPP should be allowed to displace utility generation, and to recover that energy from utility generation at some other time. The Board recognizes that hydroelectric power plants can store energy but it is not convinced that SPP energy would actually be stored. Therefore, for the present, it regards the energy exchange under net energy billing as more in the nature of a banking arrangement that the utility provides as a service to the SPP. If during a normal billing period (probably quarterly) the SPP consumes more energy than it produces, then the SPP would be billed at the usual rates for *net* energy supplied. If the SPP produces more energy during a normal billing period than its own requirements, then the utility should compensate the SPP for excess energy at the true value of the energy to the utility and its other customers. Normally this value will be the utility's avoided cost and will be less than the rate charged for net energy supplied to the SPP.

---

[1] The Board recognizes that the effect is real but is probably so small as to be lost among all the other loads continually varying on the system.

In determining the true value of such surplus energy, the Board believes there could well be some capacity contribution by an SPP but the value of any such capacity cannot be determined at this time. However, the Board believes any capacity contribution would almost certainly be more than compensated by the reduction in energy cost to the SPP under net energy billing. The Board believes that any cost to the utility of foregoing the energy charge for kWh the SPP produces for itself would be minimal, but in any case is a reasonable cost during the experimental period for this form of energy conservation. The utility in turn should recover through demand charges and connection contribution its true cost of capacity that the SPP load imposes, just as it would for any other with a similar service. This may be covered by the fixed charges for service or, in some cases, by some form of demand metering; but the Board believes it should be a true utility capacity cost and should not diminish the value of SPP-generated electricity. If the utilities are convinced the present rate structure does not adequately cover cost of capacity in such circumstances, the Public Utilities Board should be asked to determine an appropriate rate.

As stated previously, there are some benefits to the AIS of SPP-installed capacity that are not quantifiable at this time but would be compensated by net energy billing. The Board believes that TransAlta's suggested avoided fuel cost calculated on the basis of 50 per cent gas-fired energy and 50 per cent coal-fired energy is a suitable compromise as compared to the most expensive avoided fuel on the AIS. Savings in line losses at the transmission as well as the distribution level may exceed 5 per cent, but 5 per cent is appropriate during the trial period. The Board believes that it would be fair to SPPs in the interim and also without substantial subsidy by the utilities and their customers. Furthermore, this rate should be reviewed and adjusted as the cost of service is adjusted by the Public Utilities Board from time to time. The Board makes this recommendation without prejudice to the true impact of SPPs that may be determined over the trial period. The Board also notes that an SPP must recognize that further study may show that the value of an SPP to the AIS using this approach is overrated and lower credits might be implemented after the trial period. Correspondingly, if the benefits are clearly demonstrated to be higher, the credits to the SPP for surplus energy may be increased.

Trial Period

As noted before, and until more complete information is available, the Board believes this simple procedure favours the SPP that improves energy conservation by reducing load on the AIS or by generating surplus energy. The utilities may be carrying some small cost over the experimental period and both the period and the number of SPPs should be modestly restricted. The Board believes the experimental period, during which the utilities should ensure that adequate information is obtained and discussed with SPPs and the Board, should be for about five years until 31 December 1989. Such a period would allow for several other SPPs to be connected to the AIS after the Sinnott machine is in service, and still allow several years for evaluation of such SPPs. Should the number of SPPs increase much more rapidly than presently expected, the experimental period should end sooner and the whole question of equitable cost and the economics of conservation should be reviewed.

The Board recommends that, if and when the number of SPPs on the AIS reaches 150 or the total connected SPP generation equals 10 000 kilowatts, the experimental period should end and a report of their impact should be rendered. Furthermore, the Board believes the total SPP generating capacity connected to any one distribution feeder should not exceed half the utility substation supply capacity to that distribution feeder unless the utility operator can satisfy the Board that some other amount is more appropriate.

During the experimental period each utility, assisted by SPPs on its system, should obtain technical and cost information on the operation and interaction of SPPs with the AIS and submit to the Board an annual report by 31 March on the operations to the end of the previous year, and a final summary report by 31 July 1989.

Interconnection Costs

The Board believes that all interconnection costs incurred by the utility beyond those required to connect a customer of similar service, size, and class should be paid by the SPP. Costs of special test metering during the trial period should be borne by the utility. In addition, all costs incurred by the SPP to allow the safe and reliable operation of its generation as part of the AIS should be borne by the SPP. The basic premise on costs should be that all parties agreed that neither the SPP nor the utilities should subsidize one another. Matters relating to liability and insurance were raised at the hearing. The Board believes these matters relate to a normal business transaction between the SPP and the utility and should be resolved between the parties, but suggests that the utilities take into account their treatment of existing customers who have installed standby generation. The Board recognizes and accepts that all parties are entitled to and must protect their own interests, but would hope this can be accomplished without resorting to a purely legalistic approach.

SUMMARY

The Board found that some of the issues raised to date may be relevant but their impact is indeterminable at this time. However, three points did stand out from all the discussion and argument about the impacts and relationships of a small power producer and an electric utility.

- A small power producer generating wind-powered energy cannot fully utilize and conserve such energy for its own purposes without some means of matching the availability of that energy to the small power producer's own load. Such means of matching are not available at reasonable cost independent of the larger interconnected electric system.
- An electric utility is a customer-oriented regulated enterprise that provides needed electric service at the lowest reasonable cost. Over the years to date, electric utilities have been innovative in meeting the needs of their customers through new types of services and the development of new forms of contracts that recognized the true cost of providing service.
- The parties agreed that they should not subsidize one another, and that each should be able to pursue its business without acquiring costs or benefits of the other party. There appeared to be no quarrel with charging or paying for actual costs or benefits — what disagreement there was arose from different understandings and perceptions of impacts, costs, and benefits.

The Board concludes the available evidence at this time does not provide an answer as to the true impact of SPPs on the AIS. The Board does not consider it proper to impose a compromise somewhere between the opposing perceptions of reality. What should be provided is the service the customers need, and the Board sees this as a banking service by utilities for wind-generated electricity and not as storage on the interconnected electric system. Naturally, there is a cost to providing such a service and the true cost remains to be determined. In the interim, a simple means of implementing the service on a trial basis for five years has been put forward. The banking service will probably not result in a perfect matching of customer generated energy with customer load, and any net energy supplied by the utility should be charged at normal utility rates and any net surplus energy generated and delivered to the utility should be at the avoided energy cost actually realized by the utility. The basis for determining the latter is proposed to be at 50 per cent gas-fired energy and 50 per cent coal-fired energy, plus about 5 per cent credit for avoiding line losses. Actual rates should be determined by the Public Utilities Board and adjusted as required.

NON-CONVENTIONAL FINANCING OF CANADIAN WIND PARKS

by

J. C. Shepherd

INTRODUCTION

The fact is that wind parks are not economically viable in Canada on present numbers. Without any unique approaches, wind power can be produced in quantity at about 15¢ per kilowatt hour or more. Even such a number assumes some fairly good variables i.e. an installed cost per kilowatt of $1,600, amortized at 12% over 20 years, 8% operation and administration costs, 2,100 annual kilowatt hours of production per rated kilowatt of capacity (a 24% conversion efficiency), and negligible transmission losses.

There are really only four variables affecting the economic viability of large wind power installations:

1. Wind, Speed and Consistency: At the present time, there are enough good sites that this problem can be effectively dealt with by careful site selection.

2. Reliability and Efficiency of Wind Turbines: From a financial point of view, this problem is solved totally when manufacturers give power production guarantees that accept all risks except the risk that the wind will blow. However, from a security of power supply point of view, this problem will really not be solved until the manufacturers have demonstrated over the long term that their technology and their quality control have both been significantly improved.

3. Buy-back Rates: The price at which utilities will buy power has been and will continue to be a serious problem for wind power generators. Aside from lobbying and careful attention to the analysis of the power companies' own figures (since their accounting methods are sometimes unusual), the only apparent solution to buy-back rates that are too low is to trade off social or economic benefits (e.g. jobs) for a guarantee of reasonable buy-back rates.

4. Installed Cost per Kilowatt: This area, which can dramatically affect the cost per kilowatt hour, is susceptible to the use of non-conventional financing techniques to reduce the effective capital cost of wind power installations.

This paper is about non-conventional financing techniques using tax benefits and government incentives to reduce installed costs. It focuses on two main issues. In the case of tax benefits, the problem is how to convert them into cash, since for the most part the persons promoting or benefitting from wind power facilities do not have sufficient tax liabilities to get an immediate benefit from tax breaks. In the case of government incentives, the problem is somewhat different. Wind parks do not produce many jobs per dollar invested, and it is, therefore, difficult for the wind park developer to offer the government the right socio-economic trade-offs necessary to obtain government funds.

TAX-ASSISTED FINANCINGS

Scientific Research

The tax benefits available for R & D remain among the most attractive in the Income Tax Act. Unfortunately, they are becoming less and less useful for wind power producers, for two reasons.

First, wind is becoming more technically mundane, and, therefore, less able to be characterized as a new or leading edge technology. Most work being done in the area is of a commercialization nature as opposed to attempts to advance or develop the underlying technology.

Second, the government has recently introduced new guidelines on what things qualify as research and development, and those guidelines, written by academicians rather than industrial researchers, essentially demand that research be done by people in white lab coats. In this regard, it should be noted that Revenue Canada's apparent softening of this stance in early October is probably more of a mirage than a reality. Their position all along has been that neither the draft guidelines that they have had since December, 1985, nor the new guidelines made public in August, 1986, constitute a change in their policy. Therefore, for example, the true colours of Revenue Canada are shown when it is realized that since January, 1986 the draft guidelines, which were secret until March, 1986, were regularly being used as a guide by Revenue Canada's technical experts looking at whether individual taxpayers' activities were R & D. Some of these activities went back as far as 1984, and yet

Revenue Canada formally required their technical experts to apply draft guidelines which had never been approved by anyone and which, in fact, were not available to the public. It was only under threat of the use of freedom of information legislation that Revenue Canada in March released those guidelines to a few members of the tax community, and they became generally known. Similarly, since the August introduction of the new and supposedly amended guidelines they have, in fact, been used by Revenue Canada despite the purported sixty day consultation period.

Because of these things, it is very difficult to determine what things constitute qualifying scientific research, or even what the rules are at any given point in time. We only know that there has been a decided shift at Revenue Canada from industrial research to basic or pure research, which shift they are, generally speaking, refusing to admit.

If the scientific research benefits are available in a particular case, they constitute a 20% investment tax credit (sometimes 35%) and a full deduction for the balance of all expenditures, including capital costs, for a total net tax benefit of between 60% and 65% depending on the province.

In order to use these in a financing transaction, the technique that would normally be employed is a limited partnership, discussed below. Because of the new rules with respect to limited partnerships, this results in a tax-advantaged investment, but not a true tax shelter, and therefore has limited appeal to most investors. There has been some talk that in these situations a general partnership structured as a true tax shelter, in which the investor's cash invested is less than his tax benefit, could be employed. As discussed below, the reaction of the market to such a structure is as yet undetermined.

In any situation in which scientific research tax benefits are being used in a financing, it is likely that the investors will require very strong comfort as to the scientific research nature of the expenditures. Given the shifting grounds on which Revenue Canada's policy is based, it is probably fair to say that in most cases investors will require a formal income tax ruling before proceeding. Unlike in the past, when it was possible in most cases to get by with an opinion from a recognized legal or accounting firm, now even when those opinions are available (and that is rarely) investors are being more cautious and looking for a letter from Revenue Canada.

Class 34 Capital Cost Allowance

A few persistent people in the wind energy community deserve credit for something that small lobby groups rarely get - a change in the income tax regulations adding wind energy facilities to the fast write-off capital cost allowance Class 34. Introduced in the Budget of February, 1986, this change was one of the few "goodies" given in that budget, alongside cutbacks in many other programs. What was striking was that it went against a consistent trend despite having no obvious large political constituency demanding it.

The result is that wind power installations can now be written off 25% in the first year, 50% in the second year and 25% in the third year. Using normal discounting assumptions, this is equivalent to receiving a grant of about 40% of the capital cost, producing a net cost per installed kilowatt of below $1,000 in some cases. Of course, this is a deferral of tax rather than a net tax saving, and must be seen in that light. By accelerating the deduction, instead of having it amortized over the perhaps twenty or thirty year lifetime of the wind turbines, the government shifts the tax deduction to the beginning of the period and offsets it with a deduction-free period thereafter. The result is that the entire revenue flow from the wind turbine is taxable, rather than being matched against depreciation deductions over the useful life of the product. A tax deferral is nothing to be laughed at, though, since it represents a significant economic benefit given to investors. As well, it is relatively easy to qualify for it and receive its benefits.

As a result of Class 34, on a good site it may be possible to produce power from wind turbines in volume at 6¢ per kilowatt hour or in that range. This starts to be economical.

Class 34 is, of course, available to purchasers, and can be used as a selling tool in many situations. It can also be used through limited partnerships and similar vehicles as a way of having the purchase by an end user or promoter financed by third parties who have high tax rates. Both the syndication structure and the purchaser-financed structure are discussed below.

Investment Tax Credits

The Income Tax Act provides for tax credits - dollar for dollar reductions of tax - in respect of the acquisition of certain capital assets for business use. The rates range from 20% to 60%, depending on the place in which the asset is being used, and for the balance of the expenditure Class 34 treatment (in the case of wind turbines) is available. The general 20% rate applies to much of eastern Canada. A 50% (reducing to 40%) investment tax credit rate applies to places such as eastern Prince Edward Island, the Gaspé, and a number of other "prescribed designated regions". A specially-enhanced 60% rate of tax credit is available for Cape Breton and the adjacent part of the Nova Scotia mainland.

The value of these tax credits can be enormous. A wind park in Cape Breton that qualified for this credit and for Class 34 would be entitled to a 60% direct tax saving plus a tax saving on the 40% balance by way of a deduction equal to 40% of that (i.e. 16% net), for a total net tax benefit of 76% of the original capital cost. If the normal cost per installed kilowatt is $1,600, that can be reduced to under $400, and in normal circumstances this will allow power to be produced at 4¢ or even as little as 3¢ per kilowatt hour, much less than the rates charged by any power corporation in Canada.

The problem with investment tax credits is that there is a restriction in the Income Tax Act preventing the availability of investment tax credits where the purpose of the investment is "producing power for sale". The purchase of wind turbines by a user will, in many cases, be eligible for these tax credits, but the purchase by a syndicate set up to sell power to users or to a utility will normally not qualify. The theory is that the activity of producing power for sale is one that is normally the responsibility of provincially-owned utilities, and were it not for this restriction the provincially-owned utilities would find financing vehicles enabling them to get federal government money for activities that are essentially their financing responsibilities.

At the beginning of the Cape Breton tax credit program, a number of projects were proposed that would have breached the producing power for sale restriction, and the Department of Regional and Industrial Expansion discussed the possibility of loosening this restriction with the Department of Finance (who have responsibility for amending the Income Tax Act). The position of the Department of Finance was that, in general, they are not giving tax benefits to anybody these days, and in particular they were not interested in considering changes to this specific restriction.

The solution is, therefore, to sell only to power users rather than to syndicates or private utilities. It is also probably possible to sell to groups of power users, so it may be possible, for example, to get the owners of factories in an industrial park to join together to own a wind park and use the power themselves.

Four problems arise in a sale to a user in this type of situation. First, users who are not in a taxable position or are tax exempt entities are in general excluded from taking advantage of these benefits. There are some structures available that allow outside investors to, in effect, "rent" their taxability to the tax exempt entity in order to use up the tax benefits, but they are very difficult structures to sell to users, because they are complex and require fundamental changes in their business organization.

Second, wheeling rights are an issue in most provinces, and unless a site can be found that is very close to a user, the ability to get wheeling rights and the cost thereof may prove to be a serious deterrent.

Third, the utilities may charge a "ratchet" fee which is basically a standby fee for the fact that their power is available while wind power is being used. In effect, they are charging a capacity charge based on having to maintain unutilized peak load availability. Some utilities may, especially if they perceive the private generation to be competitive, charge a hefty standby fee.

Fourth, and finally, where the purchaser is a taxable user, it may perceive the purchase of wind turbines as being the replacement of a manageable and acceptable annual energy cost with a very high one time capital cost. This is not always attractive, and it may be necessary to use unique financing structures to give them the economic position of purchasing power as they use it, while still achieving the tax benefits. Discussed below is a structure called a Production Note that may achieve this result, and may also facilitate financing by syndicates.

Delivery Mechanisms - Public Financings

The new and, many think, unattractive word in tax assisted financings is "risk". There are essentially two ways that tax benefits can be accessed through public financings (limited partnerships and general partnerships), and in both cases new tax rules have added significant risk to the equation. In the past, investors have steadfastly refused to invest in tax shelters that had risk, unless the risk was sufficiently hidden by the promoters that the investors did not notice it until it was too late.

The tax shelter financing structure that is currently most accepted by investors is the limited partnership. In a limited partnership, the limited partnership carries on a business or other tax-advantaged activity, and passes through the tax advantages in accordance with their respective interests. Limited partnership interests can be structured much like corporate shares, have limits on personal liability, and can even be traded in some situations.

Prior to February, 1986, limited partnerships were often used in transactions called "flips", in which an investor would put up an amount of money and receive tax benefits greater than the amount invested. Although the investor would be made technically liable to pay an additional amount to the limited partnership, no further payments would be in fact made, and the result would be that the investor would end up, in effect, "buying" a tax benefit for seventy or eighty cents on the dollar.

From the promoter's point of view, this was a good deal because the promoter could not use the tax benefit, and this was a way of converting the tax benefit into cash. Abuses of limited partnerships, coupled with similar flip-type transactions in SRTCs, led to a severe reaction against the sale of tax benefits by persons who could not use them. In February, 1986 the Department of Finance introduced "at risk" rules that prevent flip-type transactions, whether using limited partnerships or similar structures.

When the new rules were first proposed (they are still not passed), the use of a trust was proposed by some to get around the limits on flips. As widely predicted, the use of trusts was stopped by the Department of Finance even before it got off the ground. While it had some possibilities, it was unfortunate that the first few users were clearly getting benefits that the government did not want, and of a size that warranted changes to the legislation. As a result, in early October, the Minister of Finance announced that trusts and similar arrangements that got around the "at risk" rules would also be prevented.

The result is that, for limited partnerships and similar structures in which the investor's personal liability is restricted, the investor must be "at risk" for that portion of the project cost on which he wants tax benefits. If the investor wants the tax credits relating to a $100,000 capital investment, and the tax deductions on the balance, the investor must have put up $100,000 in real money, and must not have been given any guarantees, directly or indirectly, that he will get any of that money back. This leaves the investor at risk for the $100,000 less the tax breaks thereon, rather than the former situation in which $100,000 would be likely to net you $120,000 in tax savings. Extensive anti-avoidance rules prevent "cute" structures avoiding these rules. These rules have been well thought through in advance, and there do not appear to be any easy ways around them.

What is now developing in these situations is a structure in which the investors put their money into a limited partnership with significant hard assets. The structure is set up so that the hard assets are sufficiently valuable that the investors can have confidence in the ability of the promoters to finance those hard assets at an amount greater than the net after-tax amount at risk by the investors. That financing cannot be in place or committed at the time of the investment, but as long as the investor can be comfortable that it will happen at some time in the future, he is likely to invest.

To give an example, there have been a number of asset based research programmes. A promoter will raise $10 million, promising to spend $6 million of it on a building. The investors putting up the $10 million get an immediate tax saving of about

$6.2 million, leaving $3.8 million at risk. If the building can be mortgaged for $4.5 million (75%), the investors can have that money distributed to them fairly quickly, leaving them 7% in hand, and perhaps retaining a residual equity in the project for their troubles. The promoter, meanwhile, has financed his entire research project and has equity in the building, while having given up a fairly low net equity in his overall project. Typically, this structure would have the lender who provides the mortgage financing (the 45%), lending on an interim basis the 45% of the cost to the investors, so that on the day they close they actually have net cash in their pocket. Using the same example, a $100,000 investor in that $10 million fund gets $45,000 from the bank, and $62,000 in tax savings. He is, therefore, $7,000 ahead at the beginning. Once the building is up and the research program is fully operational, the bank lends $4.5 million to the partnership to finance the building and the investor's proportionate share of that is $45,000, enough to pay off the bank loan.

Similar structures can be used to finance wind parks using Class 34 benefits, and, with a number of elaborate changes, wind parks accessing investment tax credits. Again, the key is the ability to finance the capital assets. Where conventional financing is not available, it may be possible to get vendor financing. In one recent proposal a limited partnership was set up to acquire a significant number of wind turbines from a manufacturer, with the price being essentially the full list price. While uncommon, the full list price was not out of the range of reasonableness, but it allowed the manufacturer to make a heavy profit. The manufacturer in turn agreed to lend approximately 60% of the total purchase price to the investors, thus allowing them to be slightly in pocket at the end of the day. My understanding in that particular situation was that the manufacturer had arranged in advance to receive from its own bank a loan, based on the security of the investor notes, equal to 70% of the face value of those notes, thus putting the manufacturer at risk for only 18% of the original purchase price. That 18% was likely to be paid at some time in the future, but could possibly not be paid. In any case, it was less than the manufacturer's after-tax profit. From the manufacturer's point of view both cash flow and net profit were very good, and the tax benefits, which could not be used by the manufacturer, were effectively sold to the investor.

Even with financing structures such as these, there is still an amount owing at the end of the day, so there is still a net amount at risk by the investor. The result is an emphasis on the business aspects of the wind farm. Contracts, including long term power sales, must be in place, and conservative assumptions must produce a reasonable rate of return over the long haul. This emphasis on the business side of the transaction, of course, is beneficial to the wind energy community, since it forces a discipline that might otherwise be difficult to keep to. However, it does mean that a lot more seed money has to be put into a major project, getting all of the bits and pieces in place, before financing can be sought. This tends to limit the accessibility of the public financing market to those who have sufficient money to get everything in place.

As can be readily seen, it may be possible to set up a conventional wind power installation that meets the business goals and therefore is able to use limited partnership financing. For research type programs, this may be an insurmountable problem, however. In order to be qualifying research, there must be uncertainty, and with that uncertainty will come significant risk. The whole structure of tax-assisted financing is now based on the financial risks being minimized by business and asset certainties, and clearly that cannot be consistent with a research activity in most cases, unless the hard assets can offset the technical uncertainty.

While the limited partnership is likely to be the preferred form over the next few years, some are now experimenting with general partnerships, since a true unrestricted general partnership is not subject to the at risk rules. A general partnership has exactly the same structure as a limited partnership, with all the same advantages and disadvantages, but with one exception: each partner is liable for all of the debts and other liabilities of the partnership. Further, under the new Income Tax Act rules, any steps that are taken to minimize that liability will likely cause the general partnership to be treated as a limited partnership for tax purposes, and, therefore, subject to the at risk rules.

The use of a general partnership is very attractive because it can be designed on a "flip" basis, in which tax benefits are simply traded for cash. On the other hand, the virtually unlimited liability associated with the general partnership may have the effect of inhibiting investments by high income individuals (who tend to be very conservative) using this structure. It will be interesting to see whether the drive to reduce taxes that sometimes consumes high income taxpayers is enough to offset the fear of contingent liabilities in investments of this sort.

Delivery Mechanisms - User Financing

Getting companies that need extensive power supply to make large capital investments is very difficult. Not only do they not like making large capital investments, but they do not see themselves as being in the business of producing power, preferring to buy power the same as they buy things from other suppliers, and they are generally unwilling to take risks on the economics of a new technology.

Assuming the potential user or group of users is able to use the tax breaks available for wind power, the solution to the capital investment question may be a Production Note. This is a structure in which a "phantom" utility is, in effect, created to sell power to the real owner of the generating facility. It is a technique that has been used in analogous situations many times, and has been talked about in the context of alternate energy, but may not yet have been used in Canada.

In order to use the Production Note structure, a single user or a group of geographically approximate users, as tenants in common, contract for the building and operation of a wind park. The vendor or promoter sells a turnkey operation to the purchaser in return for a long term note for the entire balance of the purchase price. No money is paid up front.

The note, called a Production Note, accrues interest monthly at a premium rate, perhaps prime plus 3%. Also added to the amount of the note each month is a fee, fixed in advance in a long term contract, for operation and administration costs. Normally an escalator would be applied to this, since the promoter would actually be expected to run the wind park for this fee.

The note, increasing by interest and monthly fees, would have payments as follows:

(a) when the investment tax credits available to the user are due, 85% of the amount of those tax credits;

(b) when the tax savings related to Class 34 deductions are due, 45% of those Class 34 deductions; and

(c) monthly a payment which is effectively a payment for power but is calculated as:

  (i) the lesser of the total interest and monthly fee for the month and the avoided cost of power from the utility; plus

  (ii) to the extent that the avoided cost of power exceeds the total interest and monthly fee, 50% of that excess.

The result of this structure is that the purchaser gets about 15% of his tax breaks up front, almost as a sweetener to do the deal, and he is allowed to buy power (from himself) at a price which guarantees that he would not pay more than he would otherwise pay, and gives him 50% of any savings. Of course, at the end he also owns the wind park, and so has 100% savings thereafter.

A Production Note can be self-financed by a vendor or promoter, and may, depending on the circumstances, even be pledgable at a bank. This is especially true if the creditworthiness of the user or users of the power is unimpeachable, since then the only concern of the bank is when, rather than whether, the note will be repaid. The vendor or promoter might also consider whether the Production Note can be syndicated by having it owned by a limited partnership into which investors put their money. In such a syndication, the "at risk" rules discussed above do not apply since there is no attempt to pass through tax credits or losses to the investors. The investors are merely buying an interest in long-term, high yield debt of quality borrowers. It should be noted that, using other methods of structuring the syndication (a trusteed debenture or a series of bonds), it is possible to cause the investment to qualify for investment by pension funds, RRSPs and other deferred income plans, and this market is one that to date has been untapped by the alternate energy community.

There are many variations on this type of financing, with greater or lesser risk to investors and purchasers, and varying degrees of complexity. In most cases, it is possible to design such a structure to take count of the specific circumstances and split up cash consequences, risk, and economic impact between the parties in the way they wish.

GOVERNMENT ASSISTANCE

General Comments

The other way to reduce the installed cost of wind facility is to get money from the government. In smaller projects, this is realistic, but when we are talking about "wind parks" (i.e. power on a larger scale), this is a much harder area to break into. The fact is that the purse strings are really tight right now, both federally and provincially, and there is a general unwillingness to spend any money. Federally, any amount in excess of $10 million in grants has to pass Cabinet, and that is proving to be very tough. Even projects that appear to have all of the right factors going for them are finding that getting the support of a majority of Cabinet ministers can be a major stumbling block.

In all government assistance today, it appears that the "cheap energy" imperative has ceased to be a persuasive policy objective. There is no longer the fear of expensive energy and dependence on imported energy that there was ten years ago. It is, therefore, difficult to get significant dollars from any government on that basis alone.

The real national agenda item is jobs, jobs, and jobs. The federal government has made this virtually the sole criterion of almost every project that it looks at, and generally looks at its cost per permanent job produced. A project that has a grant or forgivable loan cost in excess of $80,000 to $100,000 per permanent job is unlikely to get approval. For the most part they strive for $40,000 to $50,000 per permanent job, and often succeed. This is a problem for wind power, since wind power is capital rather than labour intensive. It is, therefore, necessary to look for other policy objectives that might be saleable, but they are few and far between. In each case you want to look at policy benefits specific to the location and circumstances of a particular project. Whether those policy objectives are political, social or economic, they are nevertheless going to be far more important to the ability to get grant funds than the economic viability or technical attractiveness of the project itself.

Cape Breton Grants

On paper, Cape Breton is definitely the place to be for government money. It is possible to get 60% grants for capital projects in Cape Breton, comprised of the normal 30% IRAP grant and a special 30% "top-up" grant that is available on essentially the same terms as the conventional grant. The 40% balance is eligible for the 60% tax credit and the balance after that (16%) is eligible for Class 34 treatment.

In theory, you could get 90.4% of your capital cost paid for by a combination of grants and tax benefits, assuming a 40% value for Class 34 benefits (60% + (40% x 60% = 24%) + (16% x 40% = 6.4%)). The reality is somewhat different. If you qualify (see below) and if you can get the bureaucracy to move for you (see below again), the reality is that you are unlikely to get a grant in excess of 40%, notwithstanding the 60% limit, and there is almost no likelihood that your total of grants and tax credits will exceed 75%.

The two problems with the Cape Breton grants are restrictions on qualification and inability to actually get the money in your hands once you do qualify.

On qualification, the DRIE legislation provides for the same "producing power for sale" prohibition that is found in the Income Tax Act. However, unlike the Income Tax Act the DRIE legislation contains a ministerial discretion to override the rule. The Department has shown a willingness to talk about using that discretion, but it is probably fair to say that, especially given the recent introduction of Class 34, it is unlikely that the producing power for sale restriction will actually be overridden by ministerial discretion except where the amounts are relatively small or the percentages of the total project costs are relatively small. Even there, the lack of significant job creation from wind parks is going to make that a difficult road to travel.

On the question of actually getting the money, the Department of Regional and Industrial Expansion has proved to be much more reluctant to spend the government's money than their public pronouncements, and those of the succession of ministers, would suggest. The people of Glace Bay and elsewhere in Cape Breton, frankly, see them as all talk and no action. The common perception in much of Cape Breton is that, from the time the Cape Breton "top-up" grants were introduced late in 1985, there was a one year window during which the policy imperative would remain important, and after that time it would be impossible to make the program work for you, even if you were technically eligible. That one year window may have been an overly optimistic estimate.

In fact, the Federal Government has a hidden agenda of cost cutting that makes getting these or any other grants very difficult. Especially where a project has a large size, like a wind park, one cannot help but realize that the detrimental impact on the federal deficit must be a significant factor.

Finally, almost as an aside, anyone looking for grants under these programs should be careful to understand in some detail which expenditures actually qualify for the grant money. The qualifying expenditures are very restricted, and it may well be that a 60% grant, even if available and approved, turns out to be only 45% or 50% of real project costs.

Atlantic Enterprise Program

Literally before any real money was spent on the Cape Breton Grant Program, it was joined (some cynical residents of Cape Breton say "replaced") by the new Atlantic Enterprise Program, covering all of the Maritimes, in which the government provides interest rate buydowns and loan insurance for worthy projects, which would in some cases include wind power installations.

The first component of the program, the buying down of the interest rate on long term loans for the capital cost of assets, is simple enough in itself. If the bank wants to charge 12%, the bank agrees to accept 6% and is compensated by the government for all but 1% of the interest foregone. Even assuming the best of all possible worlds, it is unlikely that an interest rate buy-down will be worth more than 25% of the capital cost of an asset over its life. This is especially true given restrictions on the interest rate buydown to seven year amortization periods, and to a maximum number of points.

In the second part, loan insurance, appears attractive at the outset. However, when you talk to the banks, they will tell you that they do not like loan insurance, and are unlikely to consider it worthwhile enough to improve their chances of lending you money. The problem is that they have to look to their regular security first, and only after they have collected on all of the regular security they would normally take from the borrower, can they look to the loan insurance from the federal government. At that point, they can look to the federal government only for the difference between 85% of the amount owing, and the amount realized on the regular security. The last 15% must be totally unsecured and is not covered by the loan insurance. Since that last 15% is, therefore, totally risk money, and the banks are, by their own statements, not in the business of risk capital, the program forces them to lend on other than commercial terms, and they are very reluctant to do so. It is almost inconceivable that they would do so in large amounts to a single borrower.

The one good thing about the Atlantic Enterprise Program is that all of the tax breaks are still available, so that it can be combined with other techniques. It is possible to use Class 34 benefits and the like, combined with the Atlantic Enterprise Program, to get the best possible mix of goodies. Be warned, though, that the structure of the Atlantic Enterprise Program may be inconsistent with certain types of tax shelter structures, and this may add considerable complexity to an already difficult situation. It also must be realized that money that is lent by a bank to a limited partnership is not money that has been put into the partnership by investors, and therefore, reduces the amount of tax benefits available to them. A general partnership might overcome that, but it is probably impossible to use such a financing structure without an advance income tax ruling.

The bottom line of the Atlantic Enterprise Program is that it is mainly a political program, for the most part not even taken seriously inside the government, let alone by outsiders. At the time this paper is written, the bureaucracy to administer it is not even in place, and the government does not appear to be in any hurry to do so. That is probably sensible, since the banks have made clear privately that they want nothing to do with such a program.

Other Federal Programs

Programs like the normal IRAP grants, the IRDP program, and other government funding activities providing money for research, demonstration programs, and the like, are still available, but as most people who deal with them regularly are aware, the feds are very tight on funds and are unwilling to spend them except in the clearest possible cases.

If one is insistent on going for federal grant funding for a wind park of any size, probably the best start is to make an unsolicited proposal (USP) that hits at a carefully chosen set of policy objectives that will attract a majority of Cabinet members. The analysis is primarily a political one, but especially with the changing dynamics in Cabinet over most of 1986, it may be possible to create and take advantage of a window for funds by approaching it very carefully.

Provincial Programs

Frankly, the problem with the provinces is that they generally have very little money to spend on anything, and wind power is not high on their list of priorities.

To the extent that they do want to spend any money, the provinces have much the same priorities as the federal government, except that they are provincially-related rather than nationally-related. The federal government cares about jobs in general, whereas the province cares about jobs within the province. Similarly, the federal government is interested in promoting the export of Canadian goods and technology, while any given province will be interested in promoting exports from that province, even to other provinces. There are also provincial and local imperatives that are not shared by the federal government. Those may be related to the sometimes unusual politics of individual provinces, or may relate to the specific economic mix of a province or an area within the province.

The only really significant standard program in the provinces is the venture capital legislation in several provinces providing for 25-30% grants or tax credits for investments in qualifying businesses. In Ontario, these are small business development corporations, and several other provinces have similar programs. Generally, this percentage of grant money is not enough, and unfortunately it is difficult, perhaps even impossible, to combine the grants with federal tax credits and deductions to reach an acceptable level of overall support.

The other hidden problem in most of these programs is that the provincial budgets generally allocate a limited amount of funds to these grants and credits. This may arise in the context of upper limits on the dollar amount of any individual project, usually set out in the legislation or in the regulations, or, more of a surprise for the promoter, a simple statement by the government bureaucracy that, while the project qualifies in every way for funds, the government has run out of budget and cannot spend any more on the program.

The other provincial program of significance is the Quebec Stock Savings Plan. This plan, which gives tax benefits for share investments in Quebec based companies, has been one of the most successful investment incentive programmes in Canadian history. Other provinces, and the feds, are presently studying it, and it may be copied in other jurisdictions. The program, provides tax benefits by way of deductions of 50-100% of an investment. Although it cannot be directly combined with other tax benefits, it is possible to combine it with Class 34, R & D, or other tax advantages through a dual investment structure. Shares are offered with QSSP credits, and a general or limited partnership flows the other tax credits and deductions to investors in the normal course. A number of mining tax shelters have recently been structured this way, with Quebec investors getting both the mining tax incentives and the QSSP credit when they convert partnership interests to shares.

Despite the attractions of the QSSP, the provinces generally have little money and attempts to obtain grant money from them are generally futile. As much as they want to help, and they are often much more willing to help than their federal counterparts, their hands are tied by lack of funds.

Practically, in dealing with the provinces it is probably better to use their influence to increase buyback rates rather than ask them for grant money they do not have. If a province can increase a buyback rate for wind park production by 1¢ per kilowatt hour through its influence, that is probably worth, on a tax adjusted basis, $350 to $400 per installed kilowatt off the capital cost. In a 30 megawatt wind park, that amounts to the equivalent of a $10 million grant, certainly far more than any province would be willing or able to actually give you as a grant. Since improved buyback rates can obviously be combined with all of the normal tax breaks, this is a worthwhile subject to pursue.

CONCLUSION

Wind power in Canada is probably on the verge of commercialization. As the long-term trend of buy back rates is up, with some buy back rates (B.C. being a temporary aberration, one must think) being in the 5¢ per kilowatt hour range, and as the installed cost per kilowatt, recently as high as $4,000 per installed kilowatt, and now down to in the $1,600 range, continues to drop, the economics are naturally improving. It is perhaps fair to say that in ten years it will be possible to get conventional financing for 60% to 70% of the cost of the wind park. That will make wind parks viable without resort to unique financing structures. Until then, economic viability will depend on the use of non-conventional financing techniques, in which tax benefits and government funds are used to bring the installed cost, and therefore the amortized cost of power production, down to within a competitive range.

J. C. SHEPHERD

CURRICULUM VITAE

Jay Shepherd is the partner in charge of the tax department at the Toronto law firm of Blaney, McMurtry & Stapells. After working for several years as a banker, he went back to Osgoode Hall Law School and graduated first in his class in 1978. The next year he became the first person to ever simultaneously go through a Masters of Law programme at the University of Toronto and the Bar Admission Course at the Law Society of Upper Canada.

Since commencing full time practice as a tax lawyer in 1980, he has been heavily involved in the use of tax credits and deductions in unconventional financing techniques, having participated in over sixty such financings. He has also prepared briefs to and seminars for the federal and Ontario governments on the tax system as it affects incentives and their delivery.

Many members of the alternate energy community will be familiar with Mr. Shepherd from his papers at past conferences and seminars, where he has spoken on research and development and on financing of alternate energy activities.

Jay is a director of two solar companies and one wind energy company, and is also a founding director of the Independent Power Producers Society of Ontario.

Wind and Electric Utilities: A View from Ontario

Presented at the Canadian Wind Energy Conference 86
Quebec City, October 27-28, 1986

by Amir Shalaby
System Planning Division
Ontario Hydro, Canada

1.0 INTRODUCTION AND OUTLINE

This paper is one of several presented in this conference on the commercial market for wind energy. I am pleased to be invited to tell you how we perceive wind energy in the utility industry, particularly in Ontario. Developers of wind turbines in the 1970s recognized utilities as a potential big market. The most notable utility market to adopt wind in a big way in the 1980s was California. What about utilities in Canada? In this paper, I would like to discuss the prospects for wind, using Ontario's situation as an example. The utility market for wind has evolved in two directions. Either the utility owns and operates the wind turbine, or the utility purchases electricity from independent producers. This second mode has been the dominant one in North America.

To set the scene, let's remember that Ontario is not windy. The average wind speeds rarely exceed 5 to 6 metres/second. Wind generated electricity has flourished in areas where wind regimes are much better, perhaps with average wind speeds of 9 metres/second or better. While the wind speed difference appears small, those in the wind industry know that it makes a huge difference to the power output because turbine power is a cube function of wind speed. For example, the same wind turbine will generate four times as much electricity if it were placed in California's good sites rather than Ontario's good sites.

I would now like to:

- Go over the studies for using wind energy in Ontario and review recent surveys of potential of wind energy for Canada.
- Discuss how utility planners can evaluate the worth of wind energy to the utility.
- List some of the impacts that need to be considered when a wind generator is to be connected to the grid.
- Summarize Ontario Hydro's policies re independent generators.
- Conclude by stating what we see as the market for wind turbines in Ontario.

2.0 RECENT STUDIES ON WIND FOR ELECTRIC UTILITIES

Ontario Hydro, like many other electric utilities, considered wind as an option for generating electricity. References 1-6 indicate the range of studies over the past ten years evaluating wind for electricity generation in Ontario. The Pelee island study (3), one of the earliest, found wind to be an economic resource to displace diesel only if average wind speeds were high (above 15 miles/hour or 7 metres/second), and cost of diesel was high. The conditions on the island did not justify a wind turbine. More recent studies concluded that the cost for wind generation in Ontario will be several times the cost from other large scale options, primarily because of low wind speeds. These studies continue to indicate that wind has potential to displace diesel but is not a competitive option for the interconnected bulk power system in Ontario.

On the Canadian scene, in addition to studies for Ontario, The Federal Department of Energy Mines and Resources as well as Canadian Electrical Association (CEA) also commissioned several studies in the early 1980s to evaluate the potential of wind for Canadian electric utilities. Slater Energy Consultants (7) proposed detailed modelling methods to evaluate the potential of wind for various provinces. The analysis recognized the importance of matching the utility characteristics to the wind resource and generator characteristics. They considered in their modelling wind regimes as well as the nature of the electricity system and the cost of conventional alternatives. They found that the highest potential in Canada is in Quebec. Saskatchewan, Alberta and the Atlantic Provinces also showed some potential. The study concluded that no economic potential is foreseen for the grids in Ontario, Manitoba or British Columbia.

Recognizing that the nature of the Canadian wind and utility situation is different from the U.S. and Europe, the Canadian Electrical Association (CEA) then commissioned several studies to explore the potential for wind generation that suit the Canadian wind regimes and utility situation. Montreal Engineering (8) looked at wind-hydro combinations. They examined three possible wind-hydro scenarios and its preliminary conclusions point to Newfoundland and the Northwest Territories as a potential for economic wind-hydro combinations. I understand there is such an installation on Cape Breton island.

The wind-diesel combination is another example of an option that suits the Canadian conditions. It was demonstrated in the late 70s in Ontario. It was first tested on the Toronto islands and then at a site near Sudbury (9). By the early 1980s, this combination emerged as the most likely opportunity for Canadian utilities to use wind.

To further develop the wind-diesel option, JBF Scientific Corporation looked on behalf of the CEA at the technical details surrounding the wind-diesel hybrids (10). The study reiterated the importance of simplicity and reliability for remote applications because of maintenance and operating limitations. The study identified protection concerns such as those arising during isolated operation, where self excitation can lead to abnormal voltage and frequency conditions. These detailed concerns are shared with other investigators as evidenced by discussions in in Reference (11). The JBF report also suggested ways of increasing the value of wind in a diesel supplied community.

The early wind-diesel demonstrations pointed to the efficiencies associated with the "mechanical" coupling of the wind turbine and the diesel rather than the "electrical" coupling. This arrangement is possible when a vertical wind turbine is used and it is possible to locate the turbine close to the diesel generator. Fuel savings were estimated to be substantial at wind speeds in excess of 12.5 mph (5.5 m/s) and depended on the shape of the load and nature of coupling and controls(9).

Acting on these findings, Ontario Hydro is working with Howden to operate a wind-diesel generator in the remote community of Fort Severn. The set was tested in May 1986 in Scotland and is now on site awaiting interconnection. There will be a more detailed description of that project later on in the conference.

Let me now shift from a discussion on technology and resources to a discussion on system planning consideration within the utility.

3.0 HOW CAN UTILITY PLANNERS EVALUATE THE WORTH OF WIND GENERATION

The proper evaluation of wind resources on a utility system requires a good understanding of both utility operation and planning considerations as well as of the wind resource and turbines. For a start, the wind developers talk about the turbines in terms of swept area or rotor diameter. The utilities like to think about rating in kW and costs in terms of $/kW and cents/kW.h. We recognize for example that when turbines are characterized solely on the basis of their kW rating, this may result in an improper evaluation of the contribution to the system and fuller evaluation based on energy production better complements the picture.

The early evaluations of wind by the utility industry found the intermittent nature of the resource troublesome to model and characterize. Some utilities initially chose to simplify matters by considering wind as only a "fuel saver" and ignored its contribution to capacity. As experience with wind increased so did the modeling and evaluation capability. Models that recognize the capacity value of intermittent resources are now possible to develop.

Reference (12) provides a review of this subject. Detailed methods for incorporating intermittent resources are then proposed.
Some of the findings of Reference (12) indicate that:

- Analysis that ignores contribution of intermittent resources to capacity underestimates their value.
- The value of wind energy cannot be analysed in isolation of the "system". Evaluation techniques must recognize various system operating and planning considerations.

- Despite the intermittent nature of wind generation, a credit for meeting capacity, in addition to energy, can be determined.
- The capacity credit for wind depends on:
  - How much wind generation is on the system. This is described as penetration level. The capacity value decreases as penetration increases.
  - The reliability criteria on the system. Generally, the more stringent the reliability criteria, the less credit can be given to wind generation; especially at high penetration levels.
  - Site diversity. The more geographically diverse the wind generation sites, the more credit for capacity.
  - Coincidence of resource availability and system requirements. The higher the coincidence the higher the credit. It is fortunate that the wind resources in Canada are better in the winter than the summer, presenting higher value as it coincides with winter peaking requirements of the utilities in Canada.

- A capacity credit can range from 15% to 40% (of name plate rating) of wind generator ratings. Reference (13) comes to similar conclusions for good wind regime areas with good match to system needs at low penetration levels.

Reference (12) also identified a number of factors that are relevant to the evaluation of intermittent resources:

- Intermittent resources should be evaluated at the system margin rather than be compared to base loaded plant. Reference (14) shows that Ontario Hydro holds this view in evaluating the worth of independent generation of electricity.

- The shorter lead time associated with wind has value to the utility. This is indeed true and is recognized in planning. A quantitative evaluation of a staged, short lead time option is discussed in Reference (15).

- Interaction with load management and storage options affects the value of wind.

- There are operating penalties, perhaps up to 15% arising from introduction of wind resources to an integrated system. References (16) and (17) expand on this, but initially conclude no significant problems for low (<2%) penetration levels.

The Canadian Electrical Association also commissioned a study to suggest a method for assessment of wind generation in utility applications (18). The study found that there are constraints imposed by the power system that limit the benefits of wind and have to be considered. The report finds that a purely diesel system with units that can operate at part load (say 50% of rating) is best suited to absorb wind energy benefits. The existing generation mix was found to affect the capability of a system to accept wind generation. Reference (19) shows that the existing system mix has a

significant impact on the value of wind energy and its ranking against other options.
The impact of wind generation on the reliability of supply is not generally a concern for low penetration levels. It can however become a major consideration if wind is to make up 10% or more of the total electricity supply. This could include systems like Hawaii or systems supplying isolated communities. Reference (20) explores ways of modelling the reliability aspects of wind generation.

This section reviewed how the economics of wind can be evaluated from the utility's perspective. There are many other significant impacts in addition to economics. The next two sections touch on the issues related to interconnection of wind generators with Ontario Hydro.

4.0 IMPACT OF WIND GENERATORS ON THE UTILITY

The integration of wind producers into the operation of the utility has a number of significant impacts that must be carefully considered by the utility when setting policies. Some of these issues that are relevant to independent wind generators are:

- Public and employee safety: structural integrity, and electrical isolation facilities.
- Secure operation of the wind turbine when connected to the integrated system: stability, voltage control, short circuit levels, synchronizing, communications, telemetering, and a host of other technical considerations to ensure proper operation and maintenance.
- Assurance of long term secure supply of energy: wind turbine-generator life. This becomes an issue when a large portion (10%) of the utility generation comes from wind.

5.0 ONTARIO HYDRO'S POLICIES RE INDEPENDENT GENERATION

Ontario Hydro encourages the development of independent generation that is beneficial to the people of Ontario. To support this objective, Ontario Hydro:

- Provides technical assistance.
- Interconnects with independent generators.
- Buys generated electricity at rates that reflect its long term value.

To explain policies and service conditions to those interested in developing private generation, Ontario Hydro publishes three information items entitled "Selling Power to Ontario Hydro", "Parallel Generation Rates and Service Conditions" and "Parallel Generation Interconnection Requirements". The phone numbers of our Regional Marketing Managers who are the customer contacts are listed. The publications also explain a number of issues, including:

- The Purchase Rate Schedule
- Purchase Arrangements
- Metering
- Procedure for Approval
- Wheeling
- Costs Borne by Parallel Generator
- Technical Requirements

Copies of these publications can be obtained from Hydro's Public Reference Centre and from the Regional offices.

The rates paid by Ontario Hydro in 1986 are summarized as follows:

Standard Rates

3.45 cents/kW.h for high capacity factors
2.45 cents/kW.h for low capacity factors

Optional Rates

There are optional rates for:
- Peak and off-peak hours
- Summer and Winter
- Energy and capacity

For wind generators, the lower rate will probably apply. There are also much higher rates offered at remote diesel supplied communities. For example 40 cents/kW.h is being offered at Fort Severn.

Reference (14) expands on how the value of electricity to Ontario Hydro is evaluated.

6.0 FUTURE PROSPECTS FOR WIND GENERATORS IN ONTARIO

The wind research and development effort in the late 70s and early 80s was directed to developing large scale multi MW machines for utilities (21) and (22). This was the case in the U.S., parts of Europe and to some extent, in Canada as well. More recently, by the mid-1980s, the mid range turbines in the 100-600 kW size emerged as the commercially suited option for utility applications (23) and (24). There are economics of scale to be captured, but only to a certain extent. This is because there are still problems to be overcome with the large machines. Their size and weight make them expensive to manufacture, transport, erect and maintain. There are also unanswered questions about fatigue related problems and complex controls. These factors are making multimegawatt machines expensive to build and operate. On the other front, there are challenges to the small and mid-range developers and operators. The challenges include clever siting and operation to fully harvest the wind resource, producing cheaper machines, and lowering operation and maintenance costs.

The wind industry is now firmly established as a commercially viable option in places like California. The industry may be on its way to achieving low costs of say $1000-2000/kW for the wind turbines and 1-2 cents/kW.h for operation and maintenance. Even at such costs, which are much lower than only a few years ago, wind still cannot compete with conventional generation sources in Ontario.

This is partly because the wind generators are expected to operate 20% of the time. The utility therefore will have to complement wind with other generation sources to meet electricity demands round the clock. The other reason wind is not competitive in Ontario is the low wind speeds. Many of the commercially available turbines reach their rated output at say, 10 to 12 m/s and operate at only to 20% of their rating at 5 to 6 m/s.

There will undoubtedly be further developments, such as variable speed turbines, reduced cost in designs and better controls that will enhance the economics of wind turbines.

The economics are promising in Ontario for remote sites where the wind regime is good and diesel is expensive.

Despite the expected technology and operating advances, there is no escape from the fact that Ontario is not windy. This situation makes wind-diesel hybrids in remote communities the likely application for wind generated electricity in Ontario.

References

(1) Kirby, J.J. "A Review of Large Scale Power Generation Using Wind Mills", December 1975. Ontario Hydro D&D report #75117.

(2) Brown, C.K. and Higgin, R. "Preliminary Assessment of the Potential for Large Wind Generators as Fuel Savers in AC Community Diesel Power Systems in Ontario" Ontario Research Foundation, Mississauga March 1976.

(3) Drewes, P.L. and Barnstaple, A.G. "Wind Power on Pelee Island" Ontario Hydro D&D Report No. 77227.

(4) Drewes, P.L. "Wind Energy as a Source of Electricity" Ontario Hydro Report No 82353, June 1982.

(5) Phillips, B.S. and Drewes, P.L. "Remote Community Wind/Diesel Study" Ontario Hydro D&D Report No. 83105, March 1983.

(6) Drewes, P.L. "Supply Demand Options Study, Wind Generation for Bulk Electricity System", Ontario Hydro D&D Report No. 85056, February 1985.

(7) Slater Energy Consultants, Inc. et al "Potential for Megawatt scale wind power plants in Electrical Utility Systems" A study for EMR under DDS Contract No. OSQ79-00183, March 1981.

(8) Stregger, D.L. and Fisher, W.H. of Montreal Engineering "Wind Hydro Combinations" Report for the Canadian Electrical Association subject 000 G143, June 1980.

(9) DAF Indal LTD, "Development, Installation and Testing of a wind turbine diesel Hybrid" Prepared for the Ontario Ministry of Energy and the National Research Council of Canada, November 1979.

(10) Tennis, Michael of JBF Scientific Corporation "Wind Energy Applications on Isolated Diesel Systems" for the Canadian Electrical Association Report 139 G 267, September 1983.

(11) Patton, J.B. "Analysis of Utility Protection Problems Associated with Small Wind Turbine Interconnections". IEEE paper 82 WM 170-9 October 1982.

(12) Rockingham, A.P. "The Economics of Wind Mills for Large Electricity Grids" PH.D Thesis, University of London, April 1982.

(13) Sissine, F.J. "Wind Energy Development and Utility Capacity Credits: A review of Research, Implementation and Policy Issues under PURPA", Congressional Research Service, June 1984.

References (Cont'd)

(14) Shalaby, A. "Private Power Production in Ontario: Ontario Hydro's Perspective", Small Hydro 86 Conference Proceedings, Toronto March 1986.

(15) Ellert, F.J. and Heiges, H.H. "Economic Benefits of Progressive Generation". An address to the AEIC Committee on power generation, Point Verde, Florida, April 1985. Published the General Electric Company.

(16) Schlueter, R.A. et al "Analysis and Simulation of Storm Induced WELS Generation Changes on System Operation, IEEE Paper 82 WM 250-9, January 1983.

(17) Schlueter, R.A. et al "Modification of Power System Operation for Significant Wind Generation Penetration" IEEE Paper 82 WM 251-7, January 1983.

(18) Desrochers, G. of Institut De Recherche D'Hydro Quebec (IREQ) "A Method for the Economic Assessment of Wind Generator Systems in Utility Applications". CEA Report 222 G 341, August 1984.

(19) Shalaby, A. "Role of Alternative Generation Sources in Ontario", IEEE Paper No. 86 WM092-1, February 1986.

(20) Giorsetto, P. and Utsurogi, K.F. "Development of a New Procedure for Reliability Modeling of Wind Turbine Generators" IEEE Paper No. 82 WM 249-1.

(21) McGraw, M.G. "Wind Turbine Generator Systems: An Idea Whose Time has Come - Again" Electrical World, May 1981.

(22) Cadogan, J.B. and Ancona III, D.F., "Wind Turbines at Work" IEEE Spectrum, August 1982.

(23) EPRI Journal "Wind Power: A Question of Scale" May 1984.

(24) Moretti, P.M. and Divone, L.V. "Modern Windmills" Scientific American 1986.

COMMERCIAL WIND ENERGY ACTIVITY IN THE UNITED STATES

By Tom Gray, American Wind Energy Association

1. Current Status of US Development.

Wind energy development in the United States is continuing at an active pace. In particular, the last year has seen:

*Continued growth in capacity installed, although that growth is slowing. About 1,100 megawatts (MW) of wind energy equipment was installed in US windfarms at the end of 1985, and at the moment, it appears that 200-250 MW will be installed this year. While there is much discussion of the slowdown in US market growth caused by the end of the federal energy tax credits, that should be kept in perspective. Denmark, for instance, has recently established a national goal of adding 100 MW of new capacity by the year 1990. It is likely that more than 100 MW will be installed each year between now and 1990 in the US. So the American market remains quite large compared to the rest of the world.

*Continued growth in wind electric generation. The windfarms produced 660 million kilowatt-hours (kWh) of electricity during 1985, and a reasonable estimate for their production in 1986 is 1.5 billion kWh. California windfarms produced more electricity in June of this year than in all of 1984, which demonstrates graphically the rapid growth that has taken place in the industry. And again, we can look for the power production levels to keep growing in the future, though more slowly.

*Continued improvement in capacity factors and in productivity per kilowatt of installed capacity. Productivity rose from 774 kWh/kW installed in 1984 to 1,087 kWh/kW installed in 1985, an increase of 40% per turbine. Although that is still some distance from the 2,500 or so we all would like to see, it is still an impressive improvement, especially given the fact that it is not just the new machines going on-line that are doing better, but also those installed in past years. Equally important, it is now possible to find out about that improvement and to compare machines against one another through the California Energy Commission's quarterly windfarm performance reports. I strongly recommend them to anyone needing information about the track records of various types of equipment -- "Wind Energy Weekly", "Alternative Sources of Energy", and "Windpower Monthly" all carry data based on the CEC reports.

*Continued improvement in lowering O&M costs. Bob Lynette has been documenting this information for the Electric Power

Research Institute (EPRI), and his material shows an industry making steady progress toward maturity.

*Continued progress in lowering installed costs. A paper delivered recently by a representative of U.S. Windpower showed that with an installed cost of $800/kW, a 7% interest rate, and a 30% capacity factor, a windfarm could produce power for 3.9 cents (US) per kWh, which is the equivalent of $23/barrel oil. That is in a range in which a legitimate market should exist in grid-connected application, and a large market for stand-alone systems.

So we are seeing another year of substantial progress in the wind energy industry. Nevertheless, the outlook is not all rosy, and since I'm speaking here to the wind community rather than the press, let me list some of the problems I see facing us.

2. Problems on the Horizon.

*Financing of wind turbines into the long-term future is still an open question. The financing mechanisms currently in use all depend to a large extent on government subsidies in some form. Expiration of the energy credit PLUS the basic 10% investment tax credit is a heavy blow which the industry will be some time in absorbing.

*Environmental issues loom ever larger. The issue of aesthetics, which might seem relatively unimportant, is really a potential "show-stopper," according to a recent Dutch public opinion survey presented at the European Wind Energy Conference in Rome. On the other hand, we have had absolutely no problem with aesthetics in the Tehachapi Mountains, where the benefits of economic development associated with wind energy outweigh any perceived detriment to the environment.

*The price of oil remains far below peak levels of recent years, and although we in wind energy are somewhat insulated from the economic effects of oil prices, the public's interest in renewable energy has fallen off sharply, making it more difficult for us to attract political support.

*A renewed assault by utilities on PURPA (the Public Regulatory Policies Act of 1978) and third-party electricity generation appears likely in the near future because of massive cogeneration in some utility service areas. While this assault will not be aimed directly at wind energy, we will have to monitor it closely to ensure that our interests are protected.

*The "boom and bust" character of the windfarm industry has left a number of manufacturers in weakened financial conditions. In the US, four major manufacturers -- Wind Power Systems, VAWT-POWER, Enertech, and ESI -- have gone bankrupt in the last two years, and the expiration of the energy tax credits will put further pressure on the rest.

*Our industry remains concentrated in California, and therefore overly vulnerable to changes in that state's policies. At the local level, it is concentrated in 3-4 counties, which further magnifies the problem and the need to be actively involved in and concerned with politics at the county level.

*And finally, the US federal wind energy program has been retrenching for several years, largely because of our massive budget deficit. Funding has been cut steadily, in spite of the fact that there is more reason today than ever before to believe that wind energy can become commercially competitive.

3. What Does the Future Hold?

*Continued development of windfarms in California using Standard Offer 4 utility contracts which have already been signed. This development should continue for another 3-4 years.

*Development of niche markets for wind energy elsewhere. There is some utility interest in wind in the Upper Midwest for utility peaking capacity. In the Colorado River Basin, where there are plans for the addition of a great deal of pumped storage capacity, there is talk of adding wind energy because of its good technical fit with stored hydro. And of course, there is likely to be a strong market for stand-alone and wind-diesel hybrid systems in the developing world.

*Development of a global market, dominated by major firms in a few countries. Although many large corporations have left the scene, there are still some major players here and internationally -- MAN, Howden Group, Wind Energy Systems, Indal, and Hamilton Standard.

*Further movement toward institutional finance. That in turn will lead to greater maturity in the industry, because the people and institutions which lend millions of dollars will insist on proper safeguards for their investments -- a good thing for our industry.

*Development of a growing maintenance and service industry, as distinct from design and fabrication of wind turbines. Again, this is a positive development for the industry.

*Further concentration of developers in the US.

4. What can Canada Learn from Our Experience?

*Not to be too impatient with the pace of development. The global race is not over yet. No one is really venturing into wind in a BIG way (hundreds of megawatts per year), probably because it does not yet offer firm power at competitive prices.

*At the same time, it is important to be aware that a sizable investment, both public and private, will be required to develop a viable industry. In the US, nearly $2 billion has been spent on wind energy, with only a few viable manufacturers resulting. So you must not underestimate the scope of the task.

*Keep your policy house in order. Europeans today have a major advantage over the US in the policy area. Their governments have almost all made commitments to wind energy development, while ours remains addicted to the quixotic notion that the free market is the best determinant of long-term energy policy. So it is important to keep in touch with your government policy-makers, both those in and out of power, and to keep them properly educated on the importance of long term planning in this field.

*If you are able to enact further subsidies, it is essential to estimate from the beginning the length of time that will be needed and then to gradually phase them out. We failed to do that, and it has cost our industry dearly.

*Consider how best to bring the economic advantages of wind energy home to remote communities. Perhaps a foreign manufacturer (or a domestic one, for that matter) could be enticed to site an assembly plant somewhere in the North. If so, the local community would be a strong ally in the effort to develop wind energy.

*Determine how wind energy realistically fits into Canada's energy picture. Trying to push wind energy in where it does not really fit is a Herculean, and in my judgment impossible, task.

*Try to bring regulators into the game as early as possible. Wherever they may seriously affect the industry, it's good to familiarize them with the technology from the start, so that their first impression is a knowledgeable one. In San Gorgonio Pass, some of our developers were not responsible, and the result has been to seriously damage the prospects for wind energy in California's largest wind development area.

5. In Conclusion...

Because of budget deficits and other reasons, wind energy here in Canada has developed more slowly than in other countries.

That is both a curse and a blessing. It is a curse because the cost of entering this business has gone up, and is still rising. But it is a blessing because youre in a position to learn from the experience and the many, many mistakes that others have made. Now is a good time to take that knowledge and make some serious plans for the future.

Thank you.

NOTES

FOR AN ADDRESS

BY

JEFF PASSMORE

President, PASSMORE ASSOCIATES INTERNATIONAL
209-135 York Street, Ottawa, ON

Monday, October 27, 1986

Quebec City, Quebec

for

CANADIAN WIND ENERGY CONFERENCE '86

Hosted by:

The Canadian Wind Energy Association

"The Politics of Commercialization".

I could really give a short speech on this topic.

Quite simply, though we talk optimistically about legitimate remote power and export markets, the biggest single potential commercial market for Canadian wind electric power is grid connection.

Quite simply again, the biggest single impediment to the development of that commercial market is politics - and when I say politics, I want you to understand influence.

The system works on influence peddling and the plain truth is that the private power business - and by that I mean small hydro, bioenergy, photovoltaics, cogeneration and, of course, wind - hasn't, to date, had a lot of influence to peddle.
We are simply not in the energy mainstream and every time you talk to a politician, or senior bureaucratic policy maker, or utiltiy executive or just read a newspaper, that point is heavily reinforced.

I mean it doesn't matter whether we're talking about John Buchanan's impossible dream of building 4 x 150 MW coal fired facilities and exporting the power to New England, or about the Lepreau II save the Richard Hatfield premiership campaign, or the "I want another James Bay feather in my cap" Robert Bourassa strategy to help Hydro Quebec out of its current $ 21 billion debt by playing a $ 25 billion poker game. We have an outdated fixation with megaprojects in an era which can no longer sustain them economically. And these projects are almost all political interference - much of it not even endorsed by the affected utilities themselves.

Of course utilities rarely object to such political interference, because regardless of whether or not they may suspect that export markets won't develop, or that new large central facilities at this time will put them further into debt, utility jobs depend on continued utility system expansion -- irrespective of what might be happening to electricity demand.

But at the same time as all this is going on, private power producers all across the country have been independently and unsuccessfully approaching Canadian utilities in the hope of selling their electricity at what they refer to as a "fair buyback rate" (more about that later).

For example.

A British Columbia firm interested in establishing a wind park negotiated in good faith for a number of months with B.C. Hydro until they finally came to the realization that B.C. Hydro wasn't really interested;

Farmers, among others, in Alberta and Saskatchewan want a better deal from utilities than the limitations the current banking arrangement permits (and the Small Power Producers Association of Alberta is to be congratulated for its efforts on that front);

There is considerable uncertainty about what the private power policy in Ontario is going to be. This has hindered industry development as numerous potential PPPs wait and wonder;

In this province, first Ontario, and now Quebec wind companies have tried to pursuade Hydro Quebec to permit a wind farm development in the Magdelen Islands. They've bent over backwards answering and accomodating each of Hydro Quebec's concerns but instead, the utility would rather gamble on the more expensive, less proven technology of an undersea cable;

and

Small water power producers, and the Nova Scotia Forests Products Association have both been told quite plainly by NSPC that "we are simply not interested."

When these private power producers don't get the cooperation they seek from their utilities, they often turn to politicians for help. And, while a politician may be attentive - even receptive -during the presentation of the private generator's case, likely as not the President or Chairman of the utility to whom you are trying to sell will have much more influence over the politician than you do, and you're left three months, or even a year later, wondering why nothing is happening.

So what do we do? Go find another vocation?
From what I know of the private power sector in this country, you are about as likely to do that as I am likely at this point to stop speaking. So, I'll give you the long version of my speech.

I have a message for PPPs, utilities, bureaucrats and politicians.

At the outset, let me apologize to the Americans in the audience. I will have to ask you to go back to a situation which existed in the U.S. about 6 - 7 years ago. Just pretend you're having a nightmare.

So. What is the current Canadian situation?

- all Canadian utilities permit private power interconnection;
- though few Canadian utilities view private power production as a good idea, there are some who are prepared to be more tolerant;
- the price Canadian utilities pay for privately generated power is not publically determined. Hence, contention surrounds the issue of pricing because Canadian independent power producers do not feel they are being offered marginal cost for their power;
- Whereas utility planning used to be quite straightforward, future demand - both domestic and export - is now difficult to assess. In addition, generation unit costs are increasing. From a public policy perspective, therefore, private power producers see their option as far less risky.

Earlier this morning Ontario Hydro told us what utilities need and want. I'd now like to state what I consider to be both a legitimate and a politically supportable private power position.

1) The utility monopoly over the generation of electricity is improper.

   Though private power producers have no problem with the utility monopoly over the distribution of electricity (it would be totally inefficient for each producer of electricity to distribute its own power on an independently owned and operated grid), there is considerable objection to the generation monopoly. Electricity is a commodity. It is a product that can be produced using many different methods and on a wide variety of scales. Experience in Europe and the U.S. has shown that private power producers can:

   - ensure reliability of supply,
   - deliver electricity which complements the technical characteristics of the utility system,
   - offset both fuel and capital costs, and
   - provide increased flexibility by increasing the number and variety of generation sources.

   In addition, private power producers are prepared to raise their own capital. Under the current situation, the utility monopoly does not permit the market to arbitrate which projects proceed and which do not.

2) The price paid to private power producers should be based on the incremental or marginal cost of a utility's newest and/or planned central generation facility - not on average embedded costs.

   "Energy at the margin" is the operative phrase. Canadian private power producers can compete with the cost of new energy - whether its Darlington, Lepreau II, tar sands, off-shore Nfld or Fundy Tidal. Power purchase rates based on retail and/or wholesale rates are highly irrelevant and generally reflect a rate which will retard industry development. Indeed, this may be the utility's purpose. Though we do not know, for example, how Ontario Hydro arrives at its buyback rate, we do know that it seems to be consistently pegged at 85% of the wholesale rate. Such rates present a formidable barrier to development, particularly in the case of cogeneration. And if cogen has a problem at current Ontario Hydro buyback rates, what does that say about the chances for wind?

   A related point is that private power producers should be able to simultaneously sell their entire output to a utility at full avoided cost while purchasing their needs at utility retail rates.

3) Private power producers should be paid for capacity in the short term whether or not the system needs additional generation at the present time.

   With planning horizons of up to 14 years, Canadian utilities continue to overbuild at substantial cost to both themselves and to ratepayers. Ontario Hydro, for example, is basing its current planning strategy on a 13,000 MW window of uncertainty between its potential low and potential high demand forecasts for electrical consumption in the year 2000. (Ontario Hydro report "Demand/Supply Options Study", February, 1986). Private power production offers smaller generation options and thus decreases the amount of reserve margin required. Not to pay private power producers for short term capacity will inhibit private development and ensure that ratepayers continue to pay the cost of excess capacity that is characteristic of long lead time utility planning. No convincing arguement can be made to suggest there is not a considerable economic penalty associated with the fact that Ontario Hydro, for example, currently has excess capacity to 1998.

4) Private power producers should be permitted the opportunity to wheel power from one jurisdiction which does not want the power, to another jurisdiction that does. In the Canadian situation, this would be particularly useful in the Maritime provinces.

Of the above four points, the most contentious issue at the moment is "what price will private power producers be paid?" (Note I say "at the moment". Once this issue is resolved, there are a number of other problem areas to address prior to proceeding with a successful private generation project and PPPs should not kid themselves that once the pricing issue is settled it will be smooth sailing. As one B.C. client who thought we were advising him to be overly sceptical subsequently told us once it was too late, "You were right, utilities negotiate funny.").

So just what information do PPPs think should be included in calculations of true marginal cost?

Well, for starters we want to know:

- the planned in service date of the next utility central generation facility;

- the capital cost per kW in reference year dollars including interest during construction;
- fixed operations, maintenance and administration costs in reference year dollars with the utility's escalation assumptions;
- variable operations, maintenance and administration costs in reference year dollars and the correlation to energy production with escalation assumptions;
- life-cycle fuel costs per BTU in reference year dollars with escalation assumptions;
- anticipated service life for the central generation facility;
- utility interest and inflation assumptions over the lifetime of the central generation facility;

and

- the estimated transmission line capital and operations and maintenance costs required to distribute electricity from the new central facility, including escalation costs.

There's more. But I'm sure you get the point. Marginal cost calculations involve looking at more than mere capital and fuel costs. And those utilities which base buyback rates exclusively on some percent of avoided fuel cost are misleading themselves and their ratepayers.

However, before I go any further, let me make one think absolutely clear. PSGs do not want to do battle with Canadian utilities. We do not want to take the approach of some public interest groups which condemn utilities by definition. On the contrary, we want to do business with utilities, we want to negotiate commercial transactions. We are not at this stage, (and I stress at this stage) pushing for government legislation, because we feel that will set up an immediate adversarial situation that could be counterproductive.

But -- and I want to stress the "But" — we can't do business with utilities if they insist on dealing with us as a nuisance that will, with luck, go away — as mosquitos nibbling at their ankles. I mean, I have to exercise considerable patience when, as happened at a recent meeting where Ontario Hydro was asked what its avoided cost formula is, we were told (and I quote), "we don't have any intention of opening that up for discussion, we're doing the best we can, you couldn't do (the calculations) any better, don't be unreasonable." -- or at another recent meeting with Nova Scotia Power where we were told flatly "small hydro is uneconomic in Nova Scotia". Well my answer to that, of course, is that it's up to the market, not NSPC to decide what's economic and what isn't. But I actually prefer the answer given by the President of Canada's leading turbine manufacturer who said. "Of course it's not economic if Nova Scotia Power does the development."

So if utilities will stop being condescending, then I think we can do business. After all, there are three parties involved in this business - utilities, PSGs and most important of all, the ratepayers -- and all must benefit from any power purchase policy. Our view, and the view we want to have an opportunity to seriously discuss - if we could get past first base - is that the best option for all concerned is the private power option.

So what is my message here today?

Well my message to all of you is that there is obviously no question that the notion of small, independent power presents challenges to both utility and public policy planners.

To utilities then, I want to say - recognize that PPPs are serious. But more importantly, I want to say that I think this is a sterling opportunity for ambitious and visionary utility executives to show leadership and to assure their credibility with the public. It's time for utilities to re-orient the driving force within their systems away from the engineering toward the financial.

You've all heard about Oxymorons - figures of speech in which contradictory, often mutually exclusive terms are combined. Examples would be: sweet sorrow, progressive conservative, market intelligence, army food, adult education.
Well unless utilities move away from their engineering orientation the newest oxymoron in the book will have to become "utility economics".

The current monopoly situation encourages too much institutional self-interest, inefficiency and cost ineffectiveness. The challenge private sector generators would like to leave with utilities is that gradually, over the long term, they get completely out of the generation business and concentrate instead on what they do best - distribution.

To the bureaucrats in the audience who are currently managing renewable energy demonstration programs I say, you can demonstrate these technologies till you are blue in the face, but if we don't have a market oriented system there won't be any market. You have to ask yourselves what you're demonstrating these technologies for. To the federal bureaucrats in the audience I say that's a statement on post-NCAEI.

So to bureaucrats I say, facilitate,
if need be, arbitrate,
but recognize private power as a fact of life and as such,
don't vacillate.

To the political level I say, understand that somebody - preferably not future generations - is going to have to pay for all this subsidized electricity that's now on the market, and that private power production can make a contribution not only in energy terms, but in terms of economic development and deficit reduction. Also, recognize that this issue is fast becoming politically popular and the politician who first grasps this will be the early winner.

I also say to politicians, be sceptical when your utility advisors tell you that private power production is going to result in increased costs to ratepayers. The thing that results in increased costs to ratepayers are utility planned power plants originally budgeted at $ 3.8 billion that look as though they may be lucky to come on line for $ 11 billion. Small power projects which can usually be brought on line in a year or less can hardly be compared for their potential for cost overruns.

No-one believes more fervently than PPPs that ratepayers must be protected. They are the most important line in the equation. Indeed, protecting the ratepayer is the whole purpose for and ultimate outcome of marginal cost pricing.

And finally to private power producers I say, recognize that you are working at the frontier, that you are breaking ground. Stick with it, you're on a winning path. But, I want you to forget any notion you may have had that utilities are going to be leaders in this ground breaking process - that you are going to be able to walk into any Canadian utility and negotiate satisfactory contract terms and conditions for your power.

Because utilities are institutionally oriented towards central generation facilities and because, perhaps understandably, utilities do not want to take responsibility for making the avoided cost purchase rate decision, they are going to need a little push from the political level. The issue of what's right or what's wrong doesn't matter here. The decision will be a political one and utilities will learn to live with whatever decision is made. In order for the decision to be made in your favour, you are going to have to lobby. The old adage "the squeeky wheel gets the grease" has never been more true.

I should also let PPPs know just how many people are starting to see things your way and hence how much easier your lobby effort is going to be.

It doesn't matter who I talk to lately, everyone is intrigued with the concept of inviting the private sector into the electrical generation business in a significant way.

That includes:

the Canadian Chamber of Commerce, the Canadian Manufacturers Association, federal energy politicians, provincial opposition and government leaders, private sector project developers, financial consultants, Municipal Boards of Trade - they are all becoming increasingly concerned about electricity pricing, provincial deficits, utility planning and unsubstantiated claims about potential electricity export markets.

The fact is, that because we are talking about thousands of megawatts of potential power and hundreds of millions of dollars of private sector investment, the noise level is only going to increase.

The only question I have is - which Canadian utility is going to get there first - which one is going to be, for example, like Houston Light and Power -- dependent for 30 percent of its capacity on small power production?

My message, therefore, is that for the benefit of ratepayers and provincial taxpayers alike, the sooner private sector generators and utility executives achieve a working relationship the better.

The commercial reality exists at the margin. The political reality exists in organization. Soon, private power production in Canada will catch up to its predecessors in the United States and Europe. The nightmare is going to end.

RESEARCH AND DEVELOPMENT

ANALYSE MODALE DE L'ÉOLIENNE 50 kW DE L'IREQ

H. Pastorel, W. Heilmann, B. Saulnier, F. Léonard
Institut de recherche d'Hydro-Québec
1800, montée Sainte-Julie, Varennes (Québec) J0L 2P0

Conférence canadienne 1986 sur l'énergie éolienne Québec (Québec) Canada
du 26 au 28 octobre 1986

1 INTRODUCTION

Une étude théorique et expérimentale des propriétés d'une éolienne à axe vertical est décrite ici. Cette étude avait pour but de vérifier la précision d'une modélisation éléments finis, d'une éolienne à axe vertical, et de tester deux logiciels d'analyse modale destinés à l'étude expérimentale de grandes structures flexibles.

2 MODÈLE THÉORIQUE

2.1 PROPRIÉTÉ DES PALES

2.1.1 Description des logiciels utilisés

Au cours de l'étude des éoliennes à l'IREQ, il est apparu nécessaire de vérifier et de calculer les caractéristiques structurales des profils NACA. Les profils des pales de ces éoliennes présentent des épaisseurs diverses et sont munis de nervures et d'espaces vides afin de minimiser leur poids. Une série de logiciels, NACA1, NACA2, NACAGRD et SHEARC a été développée et utilisée pour calculer les propriétés des pales extrudées utilisant des profils NACA symétriques généralement utilisés dans la construction d'éolienne à axe vertical.

NACA1 [1] permet de calculer la surface d'une section transversale, l'emplacement du centre de gravité, le moment d'inertie par rapport à la corde de référence d'un profil et le moment d'inertie par rapport à un axe perpendiculaire à la corde de référence, passant soit par le point d'attaque du profil, soit par le centre de gravité du profil NACA considéré.

NACA2 [1] calcule sensiblement les mêmes propriétés mais pour un manchon d'épaisseur constante situé à l'extérieur d'un profil NACA donné. La surface intérieure de ces manchons coïncide avec un profil NACA possédant une épaisseur donnée mais leur surface extérieure n'est pas conforme au profil NACA lorsque l'épaisseur est constante.

NACAGRD [1] est un mailleur permettant de calculer les noeuds superposés sur le revêtement et les raidisseurs d'un profil NACA donné. Ces noeuds servent de données d'entrée au programme SHEARC calculant la position du centre de torsion d'un profil extrudé.

SHEARC [2] est un programme éléments finis dédié au calcul approximatif de la position du centre de torsion d'une section de pale extrudée. Tel que mentionné précédemment, la section d'une pale de rotor dans une éolienne à axe vertical est une structure à symétrie uni-axiale. Par conséquent, son centre de torsion ne coincide pas avec son centre de gravité. Pour définir un modèle correct de la pale au moyen de la méthode des éléments finis, les noeuds de cette structure doivent être situés à son centre de torsion. Une force externe créera alors un moment de torsion à moins qu'elle ne soit appliquée exactement au centre de torsion. Ce dernier aspect est surtout important lors du calcul des contraintes.

1.1.2 Résultats obtenus

Nous présentons ici les résultats obtenus sur une section typique NACA0015 employée pour les pales de l'éolienne 50 kW de l'IREQ (figure 1).

Tableau 1
Propriétés typiques de la pale de l'éolienne 50 kW de l'IREQ

Surface de la section	A	=	$7.215\ in^2$
Distance du centre de gravité au point d'attaque du profil	$\bar{X}$	=	$6.363\ in$
Moment d'inertie autour d'un axe selon la corde	I_x	=	$2.971\ in^4$
Moment d'inertie autour d'un axe perpendiculaire à la corde passant par le centre de gravité de la section	I_{ycg}	=	$111.572\ in^4$
Constante de torsion du profil	C	=	$8.807\ in^4$
Position du centre de torsion par rapport au point d'attaque du profil	$\bar{X}_{sc}$	=	$5.028\ in$

2.2 MODÈLE ÉLÉMENTS FINIS DE L'ÉOLIENNE

2.2.1 Génération de la forme exacte de l'éolienne

L'éolienne 50 kW de l'IREQ n'a pas une forme de type Troposkien mais plutôt une forme se rapprochant de cette dernière compte tenu des contraintes manufacturières d'assemblage et de pliage des pales. Afin de représenter le plus justement possible cette forme, nous avons simulé dans NASTRAN, l'assemblage d'une pale tel que pratiqué sur le site lors de l'assemblage final du rotor. La figure 2 explique brièvement le procédé employé, celui-ci a été répété pour l'autre demi-pale, les deux demi-pales ont été ensuite jointes et un modèle complet de la géométrie de la pale a été obtenu. Ces simulations ont été faites à l'aide des solutions 64 et 65 de NASTRAN.

2.2.2 Modèle éléments finis complet du rotor

Connaissant la géométrie de façon la plus exacte possible, on a généré un modèle détaillé du rotor (fig. 6). Ce modèle a été généré le plus précisément possible tenant compte pour le calcul des inerties, des inserts à la racine des pales et des manchons de renforcement et de jonction des pales (équateur).

2.3 SYSTÈME DE SUPPORT

Le système de support est constitué de six (6) haubans de 1/2 po de diamètre. Cet ensemble de haubans a été modélisé par éléments finis en utilisant le programe FEGUY [3] qui génère les données d'entrée au programme d'analyse non linéaire ADINA. En applicant, au sommet de la colonne, une force connue par incrément de charge, on a pu déduire la rigidité de l'ensemble de haubanage pour les tensions auxquelles on se proposait de faire les essais. Ces rigidités ont été rajoutées au modèle NASTRAN du rotor au sommet de l'éolienne. La figure 3 montre un exemple de ce type de calcul pour une configuration à trois haubans.

2.4 CALCUL DES FRÉQUENCES ET MODES DE VIBRATION À 0 RPM

Pour le calcul des caractéristiques dynamiques de l'éolienne, deux méthodes ont été employées:

- méthode de Ritz, connue sous le nom de "Generalized Dynamic Reduction" avec 66 vecteurs de réduction;
- condensation statique ou Guyan Reduction plus rapide mais nécessitant plus de tâtonnement avec 39 points de réduction.

Les deux méthodes, après plusieurs essais, ont conduit à des résultats identiques pour les 18 premiers modes (moins de 0.2% d'erreur), (Tableau 2).

TABLEAU 2 :

fréquences de vibration théoriques et expérimentales

de l'éolienne 50kw de l'IREQ.(en hz.)

théorique	expérimentale	erreur	description
3.22	3.35	4.0%	premier hors plan asymétrique
3.53	3.59	1.7%	asymétrique dans le plan avec mouvement de colonne
3.56	----	----	mode rigide de torsion
4.50	4.32	5%	asymétrique dans le plan sans mouvement de colonne
4.52	4.47	1.1%	symétrique dans le plan
5.86	6.11	4.26%	papillon
6.41	6.63	3.43%	asymétrique dans le plan avec mouvement de colonne
8.10	8.54	5.4%	deuxième papillon
8.17	8.50	4.0%	symétrique dans le plan
8.96	8.79	1.9%	asymétrique dans le plan avec mouvement de colonne
10.41	9.84	5.8%	premier mode de torsion

3 MODÈLE EXPÉRIMENTAL

3.1 INSTRUMENTATION

Un total de dix-huit (18) accéléromètres ont été installés sur le rotor de l'éolienne (fig. 4), agissant dans le plan du rotor et sept (7) agissant hors plan, le premier groupe servant à identifier les modes de vibration dans le plan et le deuxième, les modes hors plan. Ces accéléromètres étaient reliés à un acquisiteur de données pouvant en acquérir jusqu'à seize (16) simultanément. Les enregistrements étaient de 8000 points par canal en moyenne, à un taux d'échantillonnage de 200 à 300 points/s.

3.2 MÉTHODE D'IDENTIFICATION

3.2.1 Généralités

Pour des raisons de facilité de test, nous avons choisi d'identifier les fréquences et modes de la structure en étudiant la réponse de celle-ci à un déplacement imposé. Afin de réaliser ceci, nous avons attaché un câble à une pale qui, une fois mis sous tension, était relâché à l'aide d'un crochet d'hélicoptère commandé à distance. L'acquisition des données était alors prise au moment du relâchement du câble.

3.2.2 Type d'excitation

Si on observe attentivement les formes des modes de vibration d'une éolienne, on s'aperçoit qu'on a affaire à quatre (4) familles de modes:

- symétriques dans le plan : mode de pales;
- asymétriques dans le plan: mode de pales et colonne;
- symétriques hors plan : modes de torsion;
- asymétriques hors plan : modes papillon.

Nous avons donc utilisé quatre (4) types d'excitation correspondant à ces familles de modes.

3.2.3 Méthodes utilisées

On démontre [6] que la réponse d'une structure à un déplacement imposé est une combinaison linéaire de ses modes de vibration amortis. Partant de ceci, l'analyse en fréquence des signaux venant des accéléromètres nous a conduits à l'extraction des fréquences et modes de vibration de l'éolienne. Deux logiciels ont été utilisés:

- TSFD [5] ou "time shift frequency domain" détermine les fréquences, les modes de vibration et l'amortissement. Il utilise, un algorithme de détection de phase (spécialement adapté à l'utilisation de fenêtres à haute réjection dans le domaine de Fourier) pour la détermination des fréquences et modes de vibration, couplé à un décalage temporel des signaux de vibration avec eux-mêmes, pour le calcul des amortissements.
- Z MODAL [6] est basé aussi sur l'utilisation de FFT avec fenêtres à haute réjection, mais utilise en plus, les propriétés d'une sinusoïde amortie dans le domaine de représentation associées à la transformée en Z. Ceci permet d'obtenir à la fois, l'amplitude et l'amortissement ainsi que la fréquence pour un mode considéré.

3.2.4 Résultats obtenus

Les résultats obtenus pour chacun des modes identifiés sont indiqués aux figures 5, 6, 7 et 8. Pour les résultats expérimentaux, afin de juger de la qualité de l'identification, un facteur de confiance est attribué à chacune des modes. Pour chacun des points de mesure à chacun des modes, le logiciel calcule une amplitude et une phase. La phase associée à un mode devrait être identique en tout point à un facteur additif π près. Le calcul de l'écart type, de la dispersion angulaire de la phase, nous donne une mesure de la qualité du mode identifié. Plus cet écart type sera grand et moins la qualité du mode sera bonne.

4 CONCLUSIONS

Généralement, on observe une bonne concordance entre les résultats théoriques et expérimentaux pour les dix (10) premiers modes, toutefois:

- les modes supérieurs n'ont pu être identifiés expérimentalement à cause d'un manque d'accéléromètres sur la structure et de la difficulté de déplacer ceux existant en d'autres points de mesure;

- les modes de torsion ont été sortis avec moins de précision dans le modèle théorique à cause de la difficulté de modélisation liée à la complexité de l'arbre dans le bas du rotor.

Il faut noter que la méthode expérimentale employée a bien permis de séparer les familles de modes symétriques et asymétriques (fig. 6).

5 REMERCIEMENTS

À Yvon Vigneau, Luc Martel et Dorien Marois, techniciens du groupe Éoliennes qui ont permis par leur travail la réalisation des tests expérimentaux.

RÉFÉRENCES

1. W.J. Heilmann; "Calcul des caractéristiques structurales des profils symétriques NACA; rapport IREQ-8RT3058G, Oct. 1984.

2. W.J. Heilmann; "Étude du centre de torsion et de la constante de torsion des structures à boucles fermées et ouvertes"; rapport IREQ-8RT3028G; Fév. 1985.

3. H. Pastorel, G. Beaulieu; "Non Linear Vibrations of Guy Cable Systems", Computers & Structures, Vol. 21, No 1/2, pp. 33-50, 1985.

4. F. Léonard; "Time-Shift Frequency Domain (TSFD) Modal Analysis"; Proceeding of the 4th International Conference on Modal Analysis, 1986.

5. F. Léonard; "Une nouvelle technique d'identification modale: La Z Modal", rapport IREQ-8RT3308C, Avril 1985.

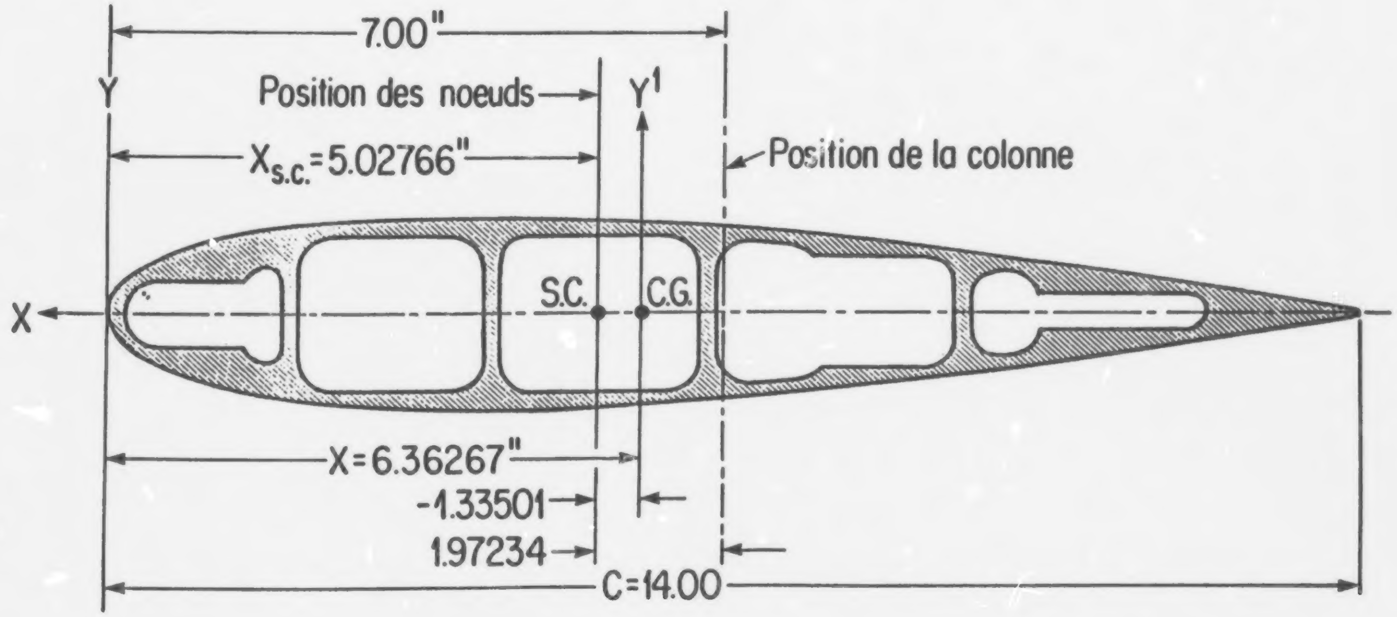

7.00"
Y
Position des noeuds
Y¹
$X_{s.c.}$=5.02766"
Position de la colonne
X
S.C.
C.G.
X=6.36267"
-1.33501
1.97234
C=14.00

Fig. 1

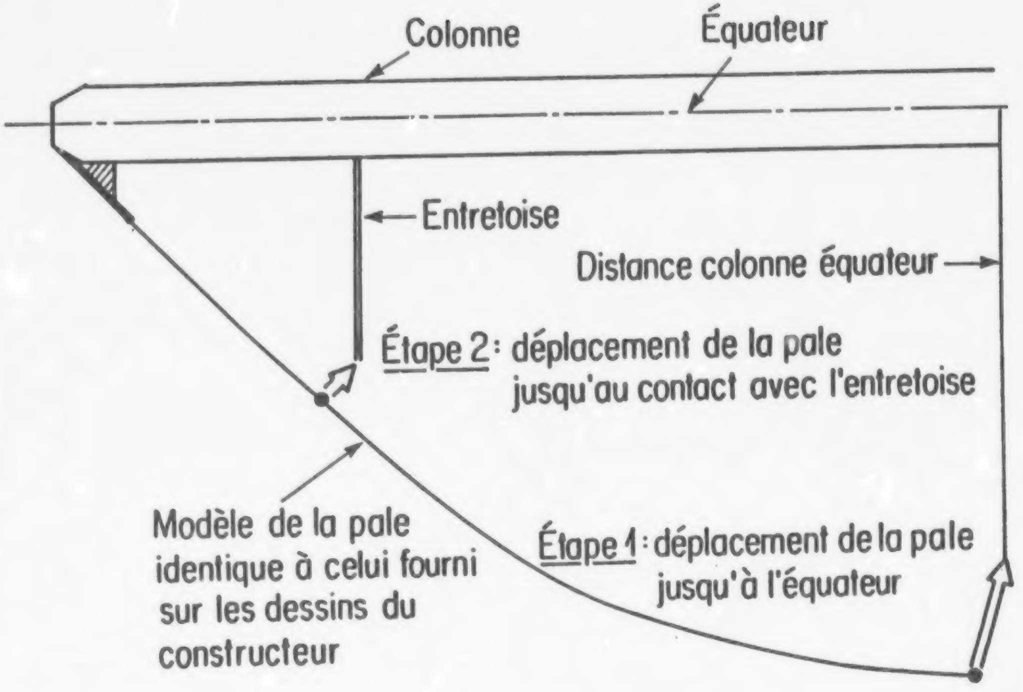

Colonne
Équateur
Entretoise
Distance colonne équateur
Étape 2: déplacement de la pale jusqu'au contact avec l'entretoise
Modèle de la pale identique à celui fourni sur les dessins du constructeur
Étape 1: déplacement de la pale jusqu'à l'équateur

Fig. 2

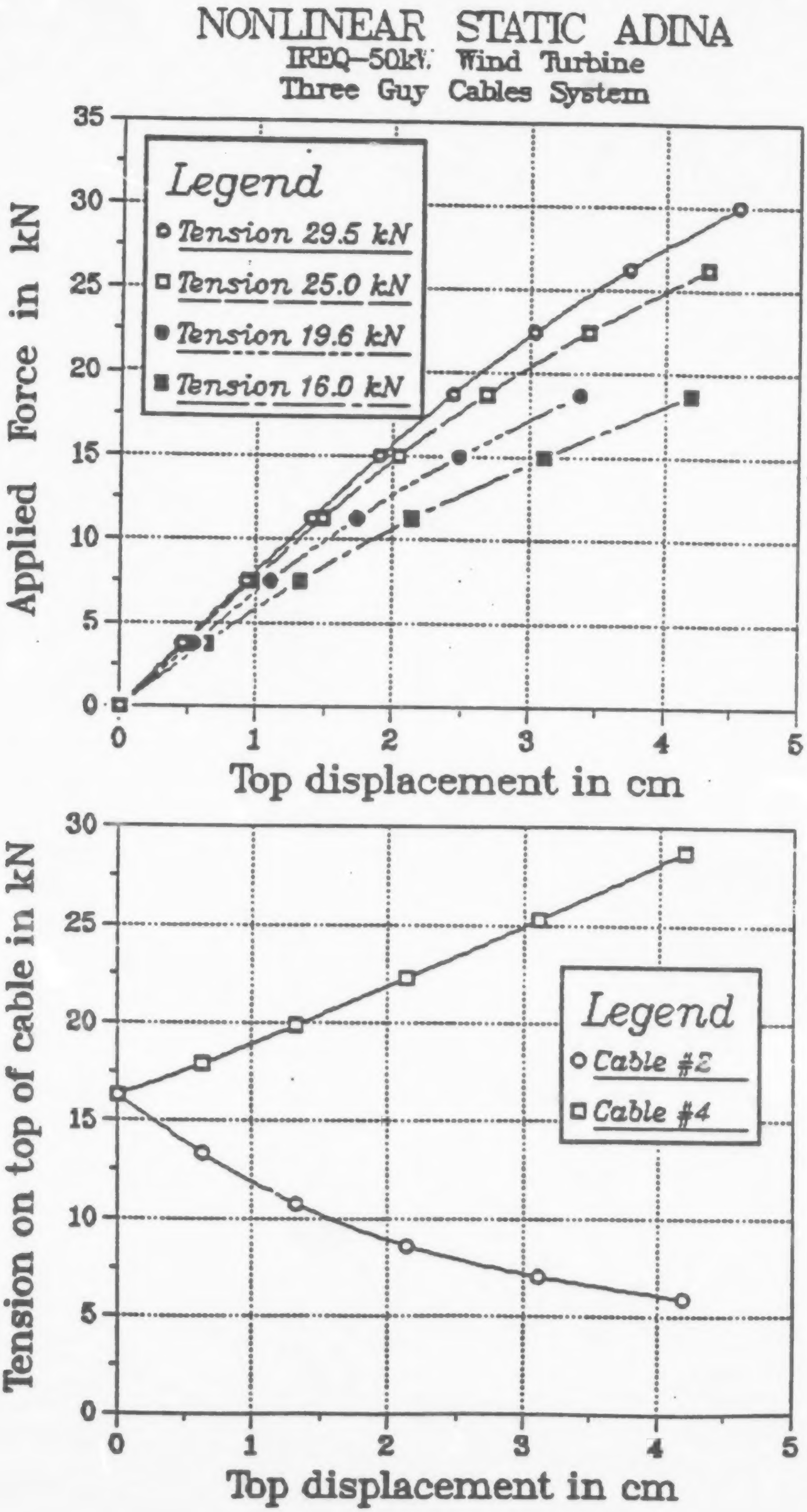

NONLINEAR STATIC ADINA
IREQ-50kW Wind Turbine
Three Guy Cables System
Legend
○ Tension 29.5 kN
□ Tension 25.0 kN
● Tension 19.6 kN
■ Tension 16.0 kN
Applied Force in kN
0
5
10
15
20
25
30
35
Top displacement in cm
0
1
2
3
4
5
Tension on top of cable in kN
0
5
10
15
20
25
30
Legend
○ Cable #2
□ Cable #4
Top displacement in cm
0
1
2
3
4
5

FIGURE 3

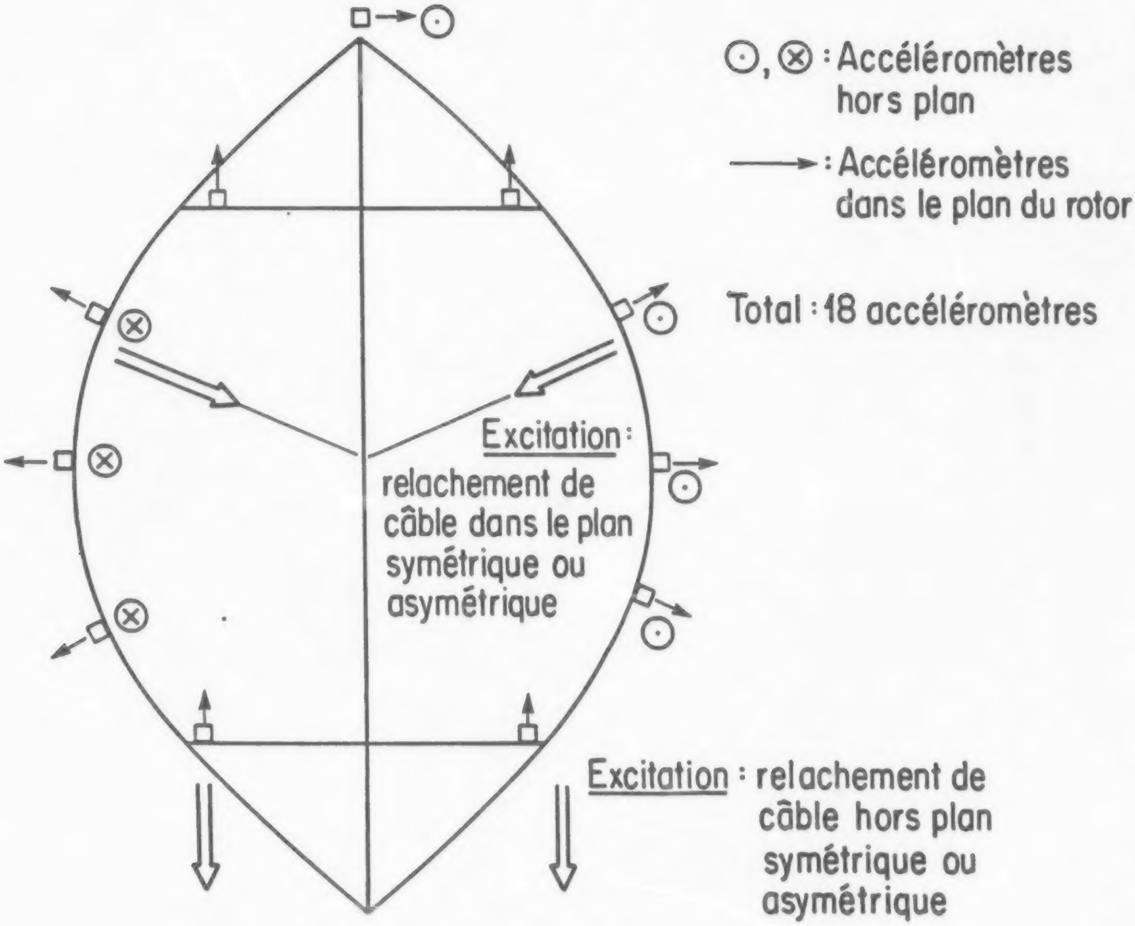
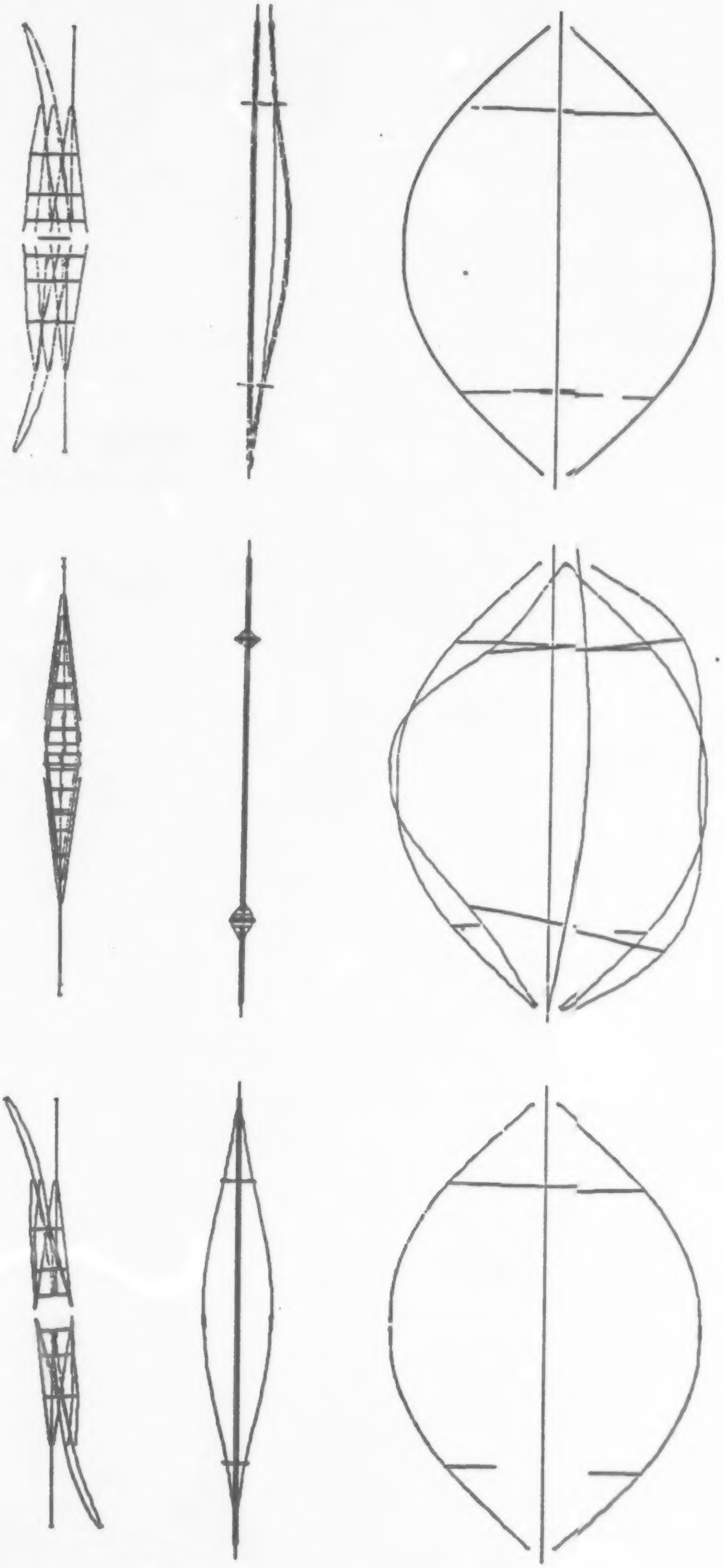

⊙, ⊗ : Accéléromètres hors plan
→ : Accéléromètres dans le plan du rotor
Total : 18 accéléromètres
Excitation : relachement de câble dans le plan symétrique ou asymétrique
Excitation : relachement de câble hors plan symétrique ou asymétrique

Fig. 4



Fréquence théorique :
3.22 Hz

Fréquence expérimentale :
3.35 Hz

Facteur de confiance :
1.3

Fréquence théorique :
3.53 Hz

Fréquence expérimentale :
3.59 Hz

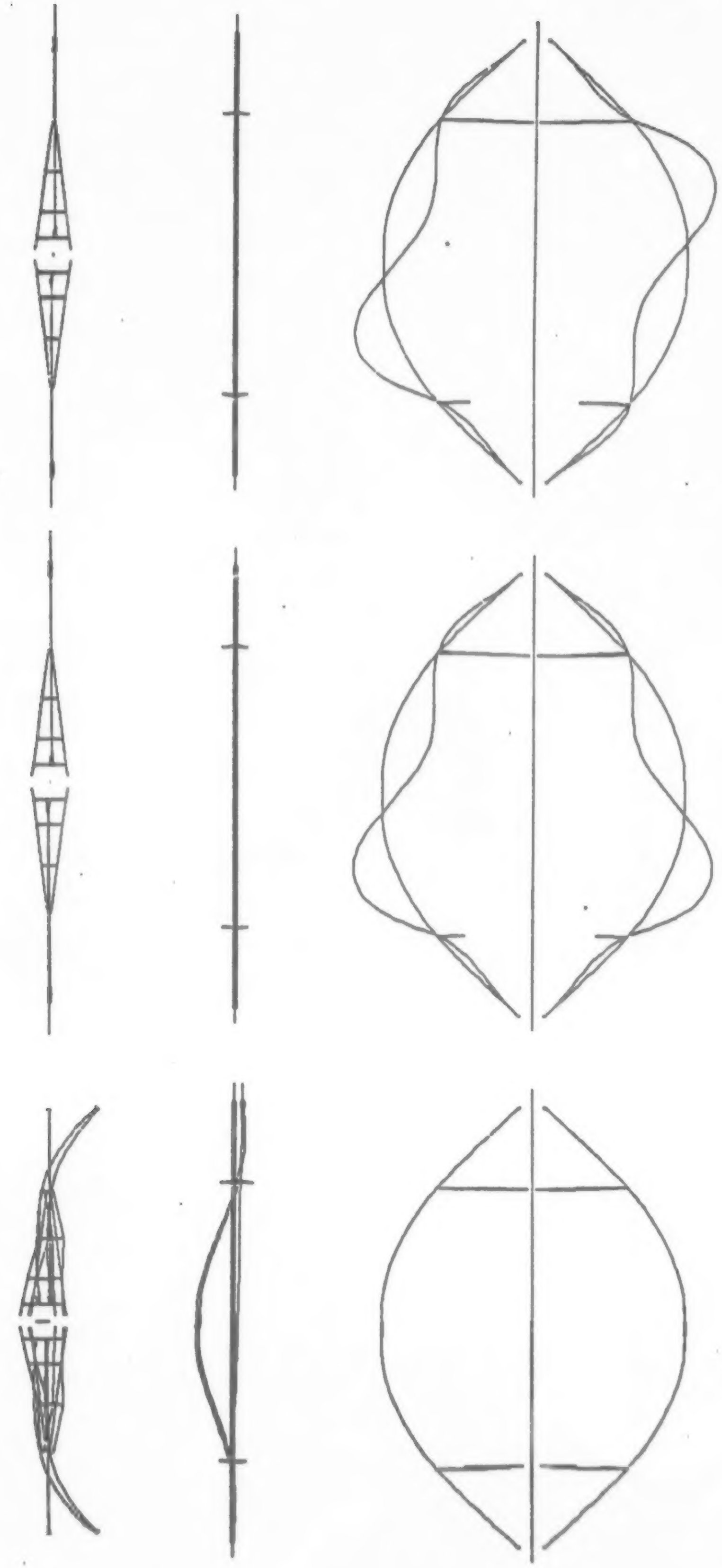
Facteur de confiance :
3.29

Fréquence théorique :
3.53 Hz

Fréquence expérimentale :
3.00 Hz

Facteur de confiance :

Fig. 5



Fréquence théorique : 4.50 Hz

Fréquence expérimentale : 4.32 Hz

Facteur de confiance : 17.39

Fréquence théorique : 4.52 Hz

Fréquence expérimentale : 4.47 Hz

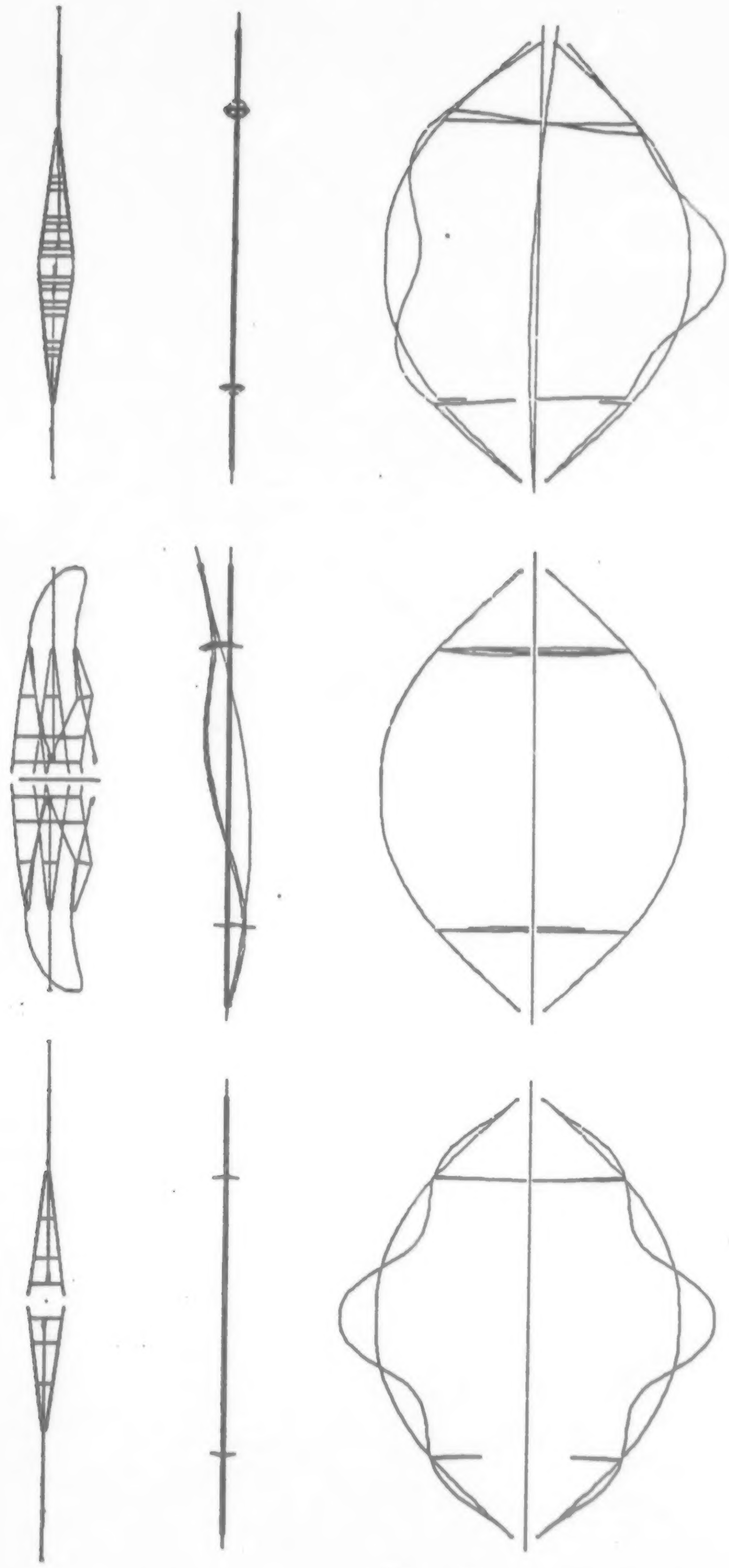
Facteur de confiance : 3.04

Fréquence théorique : 5.86 Hz

Fréquence expérimentale : 6.11 Hz

Facteur de confiance : 0.53

Fig. 6



Fréquence théorique : 6.41 Hz

Fréquence expérimentale : 6.63 Hz

Facteur de confiance : 3.07

Fréquence théorique : 8.10 Hz

Fréquence expérimentale : 8.54 Hz

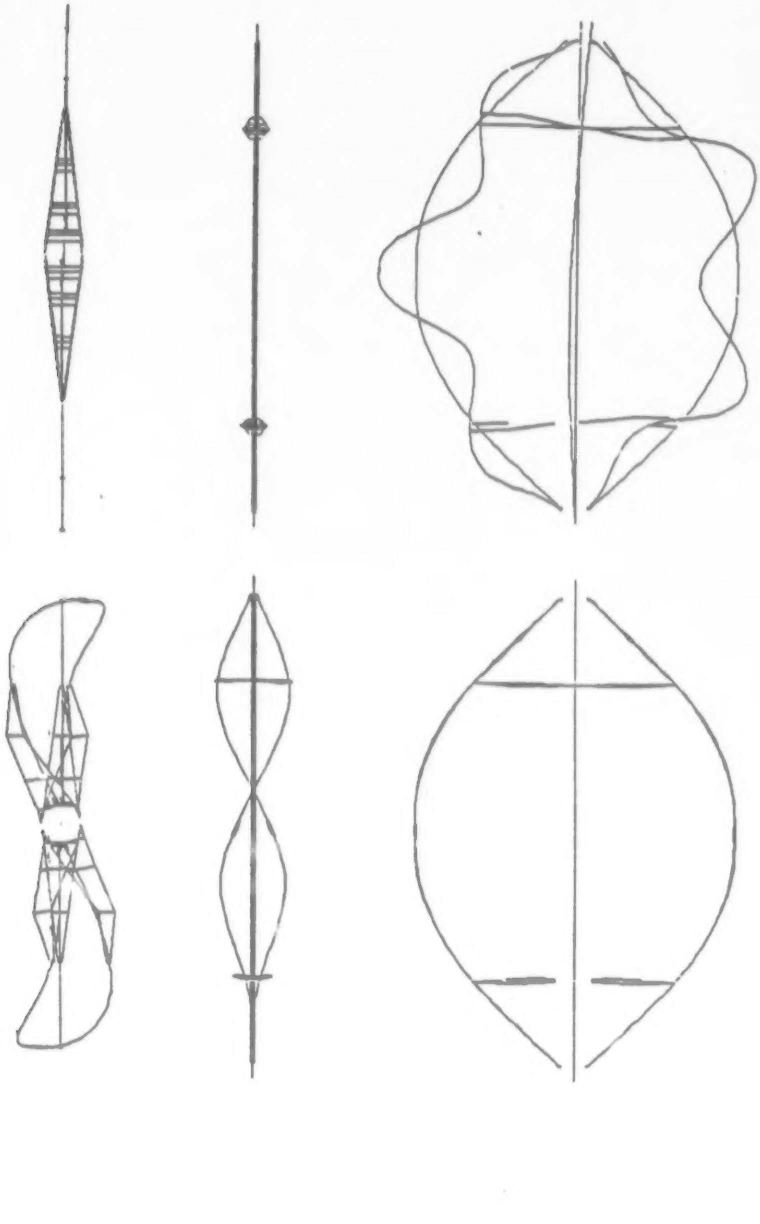
Facteur de confiance : 12.96

Fréquence théorique : 8.17 Hz

Fréquence expérimentale : 8.50 Hz

Facteur de confiance : 8.0

Fig. 7



Fréquence théorique : 8.96 Hz

Fréquence expérimentale : 8.79 Hz

Facteur de confiance : 3.5

Fréquence théorique : 10.41 Hz

Fréquence expérimentale : 9.84 Hz

Facteur de confiance : 5.7

Fig. 8

DYNAMIC-STALL MODELS FOR DARRIEUS ROTORS

Ion Paraschivoiu* and Azeddine Allet**
Ecole Polytechnique de Montréal
Department of Mechanical Engineering

ABSTRACT

Comparisons have been made between aerodynamic performance predictions using two dynamic-stall methods and experimental data for 17-M Sandia wind turbine. These dynamic-stall models are the incidence delay methods originating from Boeing-Vertol and from MIT which are based on numerical correlations of the dynamic stall delay with pitch rate parameter:

$$(\alpha_{DS} - \alpha_{SS}) / \sqrt{\dot{\alpha}_{DS}\, c/2W}$$

In comparisons of prediction against independent data sets, the Boeing-Vertol method consistently underpredicts the peak lift and pitching moment coefficients, while the MIT method appears to over-emphasise the importance of vortex shedding on pitching moment.

The MIT model calculations show that aerodynamic coefficients are understimated in comparaison with those of Gormont model, even if the shape of curves is quite the same. The MIT model provides a good prediction of the dynamic-stall regime. This is characterised by a plateau oscillating near the experimental data of the rotor power vs wind speed at the equator.

---

* Associate Professor
**Ph. D. Student

NOMENCLATURE

a: Slope of lift curve
b: Mid-blade chord, m
c: Blade chord, m
C_D: Blade airfoil section drag coefficient
C_L: Blade airfoil section lift coefficient
C_{LDS}: Dynamic-stall lift coefficient
C_{LSS}: Static-stall lift coefficient
C_m: Blade airfoil section moment coefficient
C_{mDS}: Dynamic-stall moment coefficient
M_∞: Freestream Mach number
N: Number of blades
r: Local rotor radius
R: Rotor radius at the equator, m
S_α: Sign of α
t/c: Blade relative thickness
T_L: Non-dimensionnal time at C_{Lmax} (maximum lift coefficient)
T_M: Non-dimensionnal time at C_{mmax} (maximum moment coefficient)
U_∞, V_∞: Wind velocity at the equator level, m/s
X: Local tip-speed ratio
α, α_B: Blade angle-of-attack, deg
ψ: Azimuth angle, deg
ψ_O: Azimuth angle at lift stall, deg
ϕ: Blade inflow angle, deg
$\sigma = Nc/2R$: Turbine solidity (MIT Model)
ω: Turbine rotational speed, s^{-1}

1. DYNAMIC-STALL PHENOMENON

The dynamic-stall is characterized by the shedding and passage over the upper surface of the lifting surface of a vortex-like disturbance. The phenomenon of dynamic stall remains a major problem with a variety of current applications such as airplane wings and propellers, guide vanes, subcavitant hydrofoils and wind turbine blades.

The dynamic-stall is more difficult to analyse and predict than the static-stall due to its dependence on a much larger number of parameters. The significant parameters which influence the dynamic-stall are: airfoil shape, reduced frequency, mean angle (or amplitude), Mach number, Reynold[illegible]umber, type of the motion, three-dimensional and turbulence level effects.

For a given airfoil, the primary parameter that determines the degree of flow separation is the maximum angle-of-attack. An important aspect of dynamic-stall is the large amplitudes of the motion which produce large maximum angles.

The dynamic-stall events on the Vertol VR-7 airfoil at Mach number $M_\infty = 0.25$ in a oscillatory motion $\alpha = 15° + 10° \sin\omega t$ and a reduced frequency $K = 0.10$ are presented on Figure 1. These curves show the typical hysteresis in C_L, C_M and C_D versus angle-of-attack, (1)*.

The flow in the point 1 corresponds for a thin attached boundary layer and the flow reversals within boundary layer in the position 2, Fig. 2. For the region between points 1 and 2 the lift and pitching moment follow approximately the trends of unsteady thin airfoil theory.

When the angle-of-attack exceeds static-stall angle, a thin layer of reversed flow develops at the bottom of the boundary layer. This reversed flow starts at the trailing-edge of the airfoil and moves farward to the leading-edge and then a vortex begins to evolve near the leading-edge region. In the point 3, Fig. 2, the vortex detaches and moves over airfoil surface; at this instant the vortex lift is occurs and the pitching moment diverges.

At the position 4, the vortex continues toward trailing-edge at a speed approximately 1/2 U_∞. At the vortex near the trailing-edge, lift, moment and drag coefficients reach the largest values, followed by rapid decay. Secondary and sometimes tertiary vortices produce additional fluctuations in the forces and moments, point 5, but at greatly reduced levels. If the angle-of-attack is decreasing, the flow will begin to reattach, point 6, at angle-of-attack much less than the static angle-of-attack α_{ss}. The flow becomes unseparated and the aerodynamic loads return to the linear domain.

---

*Numbers in parantheses designate References at end of paper.

In the case of the Darrieus wind turbine, when the operational wind speed approaches its maximum, all blade sections exceed the static-stall angle, the angle-of-attack changes rapidly, and the whole blade works in dynamic-stall conditions. The characteristics of static and dynamic-stall and their impact on the aerodynamic lift are synthesized on the Fig. 3 and 4. When the angle of incoming wind relative to the chordeline of the airfoil is small, the wind flow remains attached to the airfoil. When the angle-of-attack gets too large, the wind flow separates from the leading edge, causing the airfoil to stall or lose lift, Fig. 3.

The static-stall occurs when the angle-of-attack slowly changes and the airfoil gradually stalls. Dynamic-stall occurs when the wind changes rapidly and is characterized by having the airfoil stall abruptly. Dynamic-stall overdrives aerodynamic lift when α's are rapidly increasing, and underdrives lift when α's are rapidly decreasing. The abrupt changes in aerodynamic lift significantly increase unsteady blade loads that can be very damaging to the wind turbine structure.

The Darrieus vertical-axis wind turbine with curved or straight blades is a fixed-pitch device and has an unsteady complex configuration. During one rotation, the flow velocity relative to the airfoil, which consists of the vector sum of the blade speed and wind speed, varies cyclically in both magnitude and direction. This variation is further modified by the presence of induced velocities tip vortices and shed vorticity from the wakes of the blade traversing the forward half of the circular trajectory. Both the unsteady flow and the wake crossing are important factors to be considered in the estimation of the loading.

The major contribution to the unsteady aerodynamics of the Darrieus rotor is dynamic-stall, which occurs during starting or stopping at low tip-speed ratios or in sudden gusts, and its effects have a significant role in drive-train calculations, generator sizing and overall system design. Its effects can be seen in particular on the power performance curves, which exceed the steady-flow prediction for tip-speed ratios of less than 4. The ability to predict dynamic-stall is therefore of crucial importance for optimizing the Darrieus wind turbine.

The analytical prediction of dynamic-stall is still limited in its scope and prohibitively expensive. For practical reasons, effort in the helicopter industry has been concentrated on empirical methods based on oscillating aerofoil experiments, extending the potentiel flow analysis. Some dynamic-stall methods are based on empirical non-dimensional time delays $(\Delta s = 2 U_\infty \Delta t/c)$ between the stall events.

2. DYNAMIC-STALL MODELS

2.1 Boeing-Vertol Dynamic-Stall Model

No analytical model has yet been developed which is capable for predicting lift and drag in separate flow regions on the Darrieus rotor blades and so far the dynamic-stall characteristics have been approximated using the Boeing-Vertol empirical model. This stall model was developped by Gormont (2) for helicopters and is especially applicable for thin airfoils ($t/c < 12\%$) not for deep-stall ($\alpha > \alpha_{ss} + 5°$) applications.

An early modification of the Boeing-Vertol model was undertaken by Strickland (3). Sharpe (4) later used this adaptation of the Gormont model but suggested that dynamic-stall should only be considered in the calculation of the normal forces, and even then be limited to the upwind part of the rotor. Sharpe's suggestion was based on experimental results obtained at Sandia Laboratories (5).

The incidence delay methods are based on arbitrary modelling assumption and the calculation of the potentiel flow effects in the frequency domain requires the assumption that the forcing is purely sinusoidal.

All of the dynamic-stall models use empirical parameters derived from static and dynamic aerofoil tests.

In this analysis, we used the Boeing-Vertol dynamic-stall model (2) as modified by Strickland (3), which assumes that the lift-curve slope and zero-lift angle remain unchanged and that dynamic effects only modify the angle-of-attack at which stall occurs. Thus a modified angle-of-attack is utilized for entering two-dimensional force-ceofficient data. The modified angle-of-attack α_M is a function of $c\dot{\alpha}_B/(2W)$ and other parameters (α_B, γ and K_1) and is given by the relation,

$$\alpha_M = \alpha_B - \gamma K_1 \left(\left| \frac{c\dot{\alpha}_B}{2W} \right| \right)^{1/2} S_{\dot{\alpha}} \tag{1}$$

where W represents the relative inflow velocity, α_B is the effective blade angle-of-attack, γ and K_1 are empirical constants; $\dot{\alpha}_B$ represents the instantaneous rate of change of α_B and $S_{\dot{\alpha}}$ is the sign of $\dot{\alpha}$.

The instantaneous coefficients of lift, moment and drag are given respectively by

$$C_L = \left(\frac{\alpha_B}{\alpha_M - \alpha_{BO}} \right) \quad C_L\ (\alpha_M) \tag{2}$$

$$C_m = C_m\ (\alpha_M) \tag{3}$$

$$C_D = C_D\ (\alpha_M) \tag{4}$$

where α_{zo} is the effective blade angle-of-attack for zero lift. The values of γ are functions of the airfoil thickness-to-chord ratios (t/c) and the local blade Mach number. For $t/c > 0.10$ and low Mach numbers, the values of γ_L for lift stall, γ_M for moment stall, and γ_D for drag stall are

$$\gamma_L = 1.4 - 6\ (0.06 - t/c) \tag{5}$$

$$\gamma_M = 1 - 2.5\ (0.06 - t/c) \tag{6}$$

$$\gamma_D = \gamma_M \tag{7}$$

The K_1 values change with the sign of the effective angle-of-attack and are calculated by

$$K_1 = 0.75 + 0.25 S_{\alpha} \tag{8}$$

The angle-of-attack as calculated by the double-multiple-streamtube model does not take account of the turbulence of the flow. However, water tunnel observations at the French Institute IMST in Marseilles (6) show that several levels of turbulence do in fact exist in each quadrant as well as asymmetry between the left and right sides of the rotor compared to undisturbed flow. This is illustrated schematically in Fig. 5, where the larger parts of quadrants I and II are crossed by a very turbulent flow. Since turbulence delays the dynamic-stall (7) it is preferable not to take this phenomenon into account in highly turbulent zones. Rather, the double-multiple-streamtube model uses the static-stall angle (constant for one entire cycle) to estimate the dynamic-stall angle which varies with the level of turbulence. Analysis of Fig. 5 reveals a zone of low turbulence between the azimuthal angles of 135° to 15°, i.e. quadrants III, IV and part of quadrants I and II.

The turbulence in the potential flow modify substantially the dynamic-stall phenomenon. It stabilises the boundary layer then the static-stall and the dynamic-stall can occur with an angle-of-attack greater than without turbulence. In the deep-stall zone, the formation of the vortex at the leading-edge is modified or eliminated by the turbulence. The reason is that the turbulence penetrates the boundary layer by the stagnation point and stabilises the boundary layer.

For better computational accuracy with the computer code CARDAAV (8 - 10), the dynamic-stall model is therefore used for the low-turbulence zone only, i.e. between the azimuthal angles of 135° to 15°, outside this region we neglect the dynamic-stall.

2.2 MIT Dynamic-Stall Model

The Massachusetts Institute of Technology (MIT) method was chosen as the basic dynamic-stall model because of the accuracy of its prediction and because of its case of application for estimating unsteady aerodynamic loads for VAWT's. This method was modified by Noll and Ham (11) considering the Boeing-Vertol technique (1) to determine the angle-of-attack for which dynamic-stall occurs.

Experimental and theoretical work show that the primary parameter of dynamic-stall is the rate of change of angle-of-attack at the instant of stall, in the nondimensional form $\dot{\alpha}c/W$. MIT model is based on numerical correlations of the dynamic-stall delay with pitch-rate parameter $(\alpha_{DS} - \alpha_{SS}) / \sqrt{\dot{\alpha}_{DS}\, c/2W}$.

In this model it is supposed that for a given angle-of-attack, α_{DS}, as long as the angle-of-attack is increasing, the lift and moment coefficients are maintained at constant values. Thus using the Theodorsen theory of oscillating airfoil (12), it is assumed that after the angle-of-attack reaches its maximum value, the lift and moment coefficients decay exponentially to static-stall values.

$$C_L = (C_{LDS} - C_{LSS})\, e^{-(\psi - \psi_0) r / (b T_L)} + C_{LSS} \qquad (9)$$

$$C_m = (C_{mDS} - C_{mSS})\, e^{-(\psi - \psi_0) r / (b T_M)} + C_{mSS} \qquad (10)$$

where C_{LDS} and C_{mDS} are the dynamic-stall coefficients and C_{LSS} and C_{mSS} are the static-stall coefficients. ψ_0 is the azimuth position of the airfoil when the separation region was entered. The time constants $T_L = 1.0$ and $T_M = 2.5$ was approximated by Theodorsen.

In this case the dynamic-stall is an unsteady phenomenon almost independent of the airfoil motion after its initiation at the dynamic-stall angle. The separation of the flow is assumed not to start until a definite period ΔT_s, after stall angle is reached.

If the angle-of-attack is still increasing after this point, the separation state begins when the angle-of-attack starts to decrease. It is assumed that the flow reattaches at the static-stall angle α_{SS} or until ΔT_s after the initiation of dynamic-stall.

The blade element incremental lift, drag and moment, are calculated by neglecting unsteady noncirculatory and wake effects and the incremental normal force is (see Fig. 6).

$$dN = dL\cos(\theta + \phi) + dD\sin(\theta + \phi) \tag{11}$$

where θ represents the blade instantaneous pitch angle and ϕ is the blade inflow angle.

The relative wind speed is given by

$$W = \omega R\left[1 - 2X\sin\psi + X^2\right]^{1/2} \tag{12}$$

and

$$\phi = \arctan\left(\frac{X\cos\psi}{1 - X\sin\psi}\right) \tag{13}$$

For an articulated blade, the control pitch angle, θ_c can be expressed as

$$\theta_c = \theta_o + \theta_{1c}\cos\psi \tag{14}$$

where the collective pitch, θ_o, and cyclic pitch θ_{1c} are fixed values.

When the turbine rotates the tip-speed ratio undergoes harmonic variation

$$X = X_o + X_{1c}\cos\psi \tag{15}$$

where X_o is the mean tip-speed ratio given by reference (11):

$$X_o = \frac{K}{2} + \left[\left(\frac{K}{2}\right)^2 - \frac{\sigma a}{8}\theta_{1c}\right]^{1/2} \tag{16}$$

$$K = \frac{U_\infty}{\omega R} - \frac{\sigma}{8}(a + 3C_{Do}) \tag{17}$$

$$X_{1c} = \frac{K V_o}{\omega R} \tag{18}$$

V_o is the incident wind at the rotor center.

The dynamic-stall parameter $\dot{\alpha}c/W$ is used to calculate the dynamic-stall angle α_{DS} and with this angle we can evaluate the aerodynamic forces and moments. The blade element angle-of-attack is given by

$$\alpha(\psi) = \theta(\psi) + \phi(\psi) \tag{19}$$

For the articulated blade of Vertical-Axis Wind Turbine thus, we can write

$$\frac{\dot{\alpha}c}{W} = \left[\frac{\dot{\theta}(\psi)}{\omega} + \frac{\dot{\Phi}(\psi)}{\omega}\right]\frac{\omega R}{W}\,\frac{c}{R} \tag{20}$$

where

$$\frac{\dot{\theta}(\psi)}{\omega} = -\,\theta_{1C}\sin\psi \tag{21}$$

$$\frac{\dot{\Phi}(\psi)}{\omega} = \frac{-X\sin\psi + \dfrac{\dot{X}}{\omega}\cos\psi + X^2}{(W/\omega R)^2} \tag{22}$$

and the dynamic-stall parameter becomes

$$\frac{\dot{\alpha}c}{W} = \left[\frac{\dot{\theta}/\omega}{W/\omega R} + \frac{\left(\dot{X}/\omega\right)\cos\psi - X\sin\psi + X^2}{(W/\omega R)^3}\right]\frac{c}{R} \tag{23}$$

The dynamic-stall angle-of-attack α_{DS} is evaluated with the Boeing-Vertol method where the slope of the curve γ is included as a variable.

$$\alpha_{DS} = \alpha_{SS} + \gamma\left|\frac{\dot{\alpha}c}{W}\right|^{1/2} \tag{24}$$

The maximum values of the lift and moment coefficients, C_{Lmax} and C_{mmax}, respectively are calculated with the MIT method based on $\dot{\alpha}c/W$, (13,14).

$$\text{for } 0 \le \left|\frac{\dot{\alpha}c}{W}\right| \le 0.05 \qquad C_{Lmax} = 1.0 + 40.0\left|\frac{\dot{\alpha}c}{W}\right|$$

$$\text{for } 0 \le \left|\frac{\dot{\alpha}c}{W}\right| \le 0.02 \qquad C_{mmax} = -0.15 \tag{25}$$

$$\text{for } 0.02 \le \left|\frac{\dot{\alpha}c}{W}\right| \le 0.05 \qquad C_{mmax} = -0.15 - 21.0\left(\left|\frac{\dot{\alpha}c}{W}\right| - 0.02\right)$$

$$\text{for } \left|\frac{\dot{\alpha}c}{W}\right| > 0.05 \qquad \begin{cases} C_{Lmax} = 3.0 \\ C_{mmax} = -0.78 \end{cases}$$

If $|\alpha| < |\alpha_{DS}|$, the aerodynamic coefficients are calculated as a function of α using table functions for different Reynolds numbers.

If $|\alpha| \geqslant |\alpha_{DS}|$, the calculation of the aerodynamic coefficients is dependent on the time at which C_{LMAX} and C_{mMAX} are obtained.

If the maximum coefficients have been reached but peak α has not been,

$$C_L = C_{LMAX}; \text{ use sign of } \alpha$$

$$C_D = C_L \tan \alpha_{MAX} \qquad (26)$$

$$C_m = -C_{mMAX}; \text{ use sign of } \alpha$$

If the maximum coefficients have been reached and peak α is achieved, exponentially decay C_L and C_m until the static-stall angle is reached, with the expressions (9) and (10):

$$C_L = (C_{LMAX} - C_{Lss})\, e^{-(\psi - \psi_0)2R/c} + C_{Lss} \qquad (27)$$

and

$$C_m = (C_{mMAX} - C_{mss})\, e^{-(\psi - \psi_0)2R/2.5c} + C_{mss} \qquad (28)$$

C_{LMAX} and C_{mMAX} vs velocity parameter are presented on the Fig. 7.

3. DISCUSSION AND CONCLUDING REMARKS

A this stage, it's useful to underline the fact that all dynamic-stall models (Gormont, MIT) used the airfoil static data in order to calculate the aerodynamic coefficients as C_L, C_D and C_M at dynamic-stall regime. In this sens, all semi-empirical models are limited by the availability of the data.

The method of MIT presumes fully developped stall and may not be adequate for predicting aerodynamic loads and moments for incipient or light stall. The curve of Fig. 8 shows very well this tendancy. For values of wind speed V_{EQ} under 11m/s, the power is overestimed. However, for dynamic-stall regime, the effects of stall are very visible on the curves of the rotor power P vs wind speed at the equator for the Sandia 17-m wind turbine at 42.2rpm.

Like the other models (Gormont, improved Gormont) the MIT model predicts a later stall than that suggested by experimental data, according to which stall appears at V_{EQ} = 11m/s; the CARDAAV calculations give 12m/s. The reason for this is that the calculated angles-of-attack were underestimated. Moreover, the calculations indicate an abrupt change in slope, where as a gradual change in slope is identified between the linear domain and the plateau according to the experimental data. For the same wind turbine, rotating at 46.6rpm, the model still predicts a plateau near the experimental data and the linear part of the curve is overestimated,(Fig. 9). However, for high rotational speed, the curve of Fig. 10 shows that power values in dynamic-stall regime are underestimated even if the plateau still exists.

Unlike modified Gormont model which gives a linear plateau, the MIT model shows that the dynamic-stall regime is characterised by an oscillating plateau which varies near the experimental one (see Figs. 8 and 9).

An improvement to the Gormont's dynamic-stall model are introduced in this study and provide a good estimation for low tip-speed-ratios, Figs. 8-10. For a best prediction of dynamic-stall, we have neglected dynamic-stall for high turbulence zone in the Gormont model. This is based on the fact that the importance of dynamic-stall is function of the turbulence level. More experimental data will permit us to ameliorate the part of the computer program CARDAAV which is concerned by dynamic-stall. The results obtained for two rotationnal speeds (42.2 and 46.6 rpm) provide a good estimation of the real power (Figs. 8 and 9).

Since the aerodynamic data used in the MIT model are for static conditions, important effects which affect the aerodynamic characteristics may not be included. These include wake effects due to other blades, unsteady flow conditions and dynamic effects due to the blade oscillation and deformation.

The proposed stall model shows a virtually identical performance for the three rotational speeds (see Figs. 8 - 10), predicting a late stall. Moreover the curve always has the same slope, i.e. a linear part and an oscillating plateau and bears a strong similarity to the experimental curves.

As for Gormont's model, the effects of aspect ratio may improve the model predictions, specially the linear part of the curves of power. We hope that the next step of the study will include this effect in the MIT model.

ACKNOWLEDGEMENT

This work was supported in part by NSERC Grant No. A-4556 and by Energy, Mines and Resources Canada Grant No. CR-1729.

REFERENCES

1. McCroskey, W.J., "The Phenomenon of dynamic-stall", Presented to Van Karman Institute Lecture Series on Unsteady Airloads and Aeroelastic Problems in Separated and Transonic Flows, Rhode-Saint-Genese, Belgium, March 9-13, 1981, pp. 2.1 - 2.15.

2. Gormont, R.E., "A Mathematical Model of Unsteady Aerodynamics and Radial Flow for Application to Helicopter Rotors", U.S. Army Air Mobility R & D Laboratory, Vertol Division, Philadelphia, Pa., Report on Boeing-Vertol Contract DAAJ02-71-C-0045, May 1973.

3. Strickland, J.H., Webster, B.T., and Nguyen, T., "A Vortex Model of the Darrieus Turbine: An Analytical and Experimental Study", Journal of Fluid Engineering, Vol. 101, No. 4, Dec. 1979, pp. 500-505.

4. Sharpe, D.J., "Refinements and Developments of the Multiple Streamtube Theory for Aerodynamic Performance of Vertical Axis Wind Turbines", BWEA Wind Energy Conference, 1984, pp. 146 - 159.

5. Akins, R.E., Klimas, P.C. and Croll, R.J., "Pressure Distributions on an Operating Vertical Axis Wind Turbine Blade Element", Sandia National Laboratories, Albuquerque, New Mexico, 1983.

6. Brochier, G., Fraunié, P., Béguier, C., Paraschivoiu, I., "Water Channel Experiments of Dynamic-Stall on Darrieus Wind Turbine Blades", Journal of Propulsion and Power of AIAA, Vol. 2, No. 5, 1986, pp. 445-449.

7. Laneville, A., Vittecoq, P., "Effect of Turbulence on Dynamic-stall", Wind Turbine Aerodynamics Seminar, Sandia National Laboratories, Albuquerque, New Mexico, March 1985.

8. Paraschivoiu, I., "Description des logiciels CARDAA et CARDAAV pour le calcul aérodynamique des éoliennes Darrieus, Institut de recherche de l'Hydro-Québec, Rapport IREQ-8RT3010G, Varennes, Janvier 1984.

9. Désy, P. and Paraschivoiu, I., "Dynamic-stall study of the Darrieus Rotor", EPM/RT-86-21, Département de génie mécanique, Ecole Polytechnique, Montréal, Juin 1986.

10. Paraschivoiu, I., Désy, P., Masson, C. and Béguier, C., "Some Refinements to Aerodynamic-Performance Prediction for Vertical-Axis Wind Turbines", Proceedings of the 21st Intersociety Energy Conversion Engineering Conference, Vol. 2, San Diego, California, August 25-29, 1986, pp. 1230 - 1235.

11. Noll, R.B. and Ham, N.D.: "Dynamic-stall of Small wind Systems", Aerospace Systems, Inc., February 1983.

12. Theodorsen, T.: General Theory of Aerodynamic Instability and the Mechanism of Flutter. NACA Report 496, 1935.

13. Ham, N.D.: "Aerodynamic Loading on a Two-Dimensional Airfoil During Dynamic-stall. Journal of the AIAA, Vol. 6, No. 10, October 1968.

14. Ham, N.D. and Garelick, M.S.: "Dynamic-stall Considerations in Helicopter Rotors. Journal of the American Helicopter Society, Vol. 13, No. 2, April 1968.

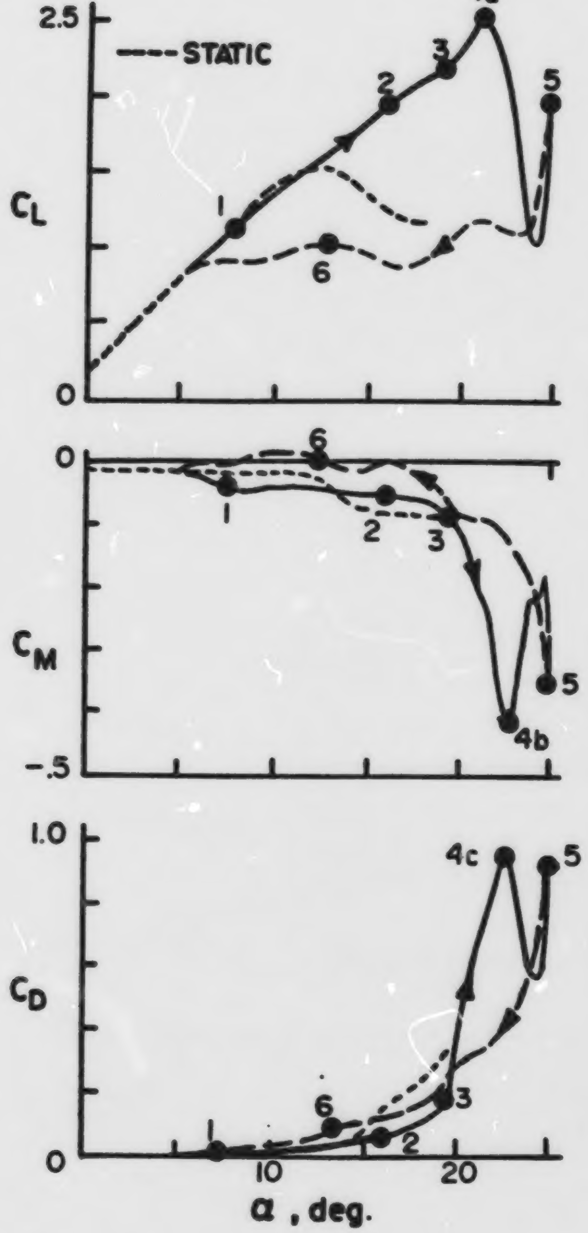


Fig. 1 Dynamic-stall loads at M = 0.25, K = 0.10, α = 15° + 10 sinωt.

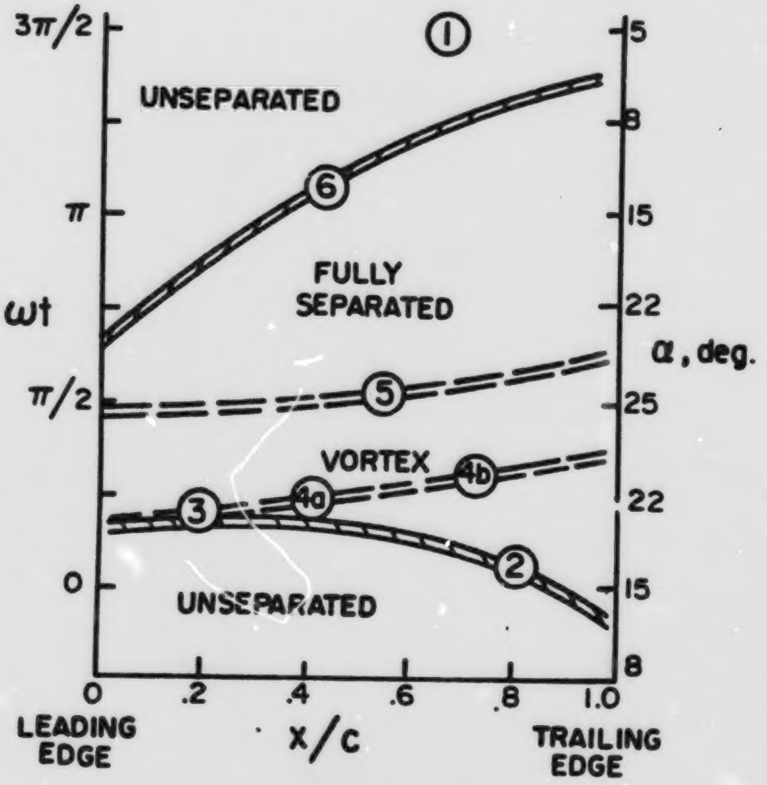


Fig. 2 Nature of flow over the upper surface (at different angle-of-attack).

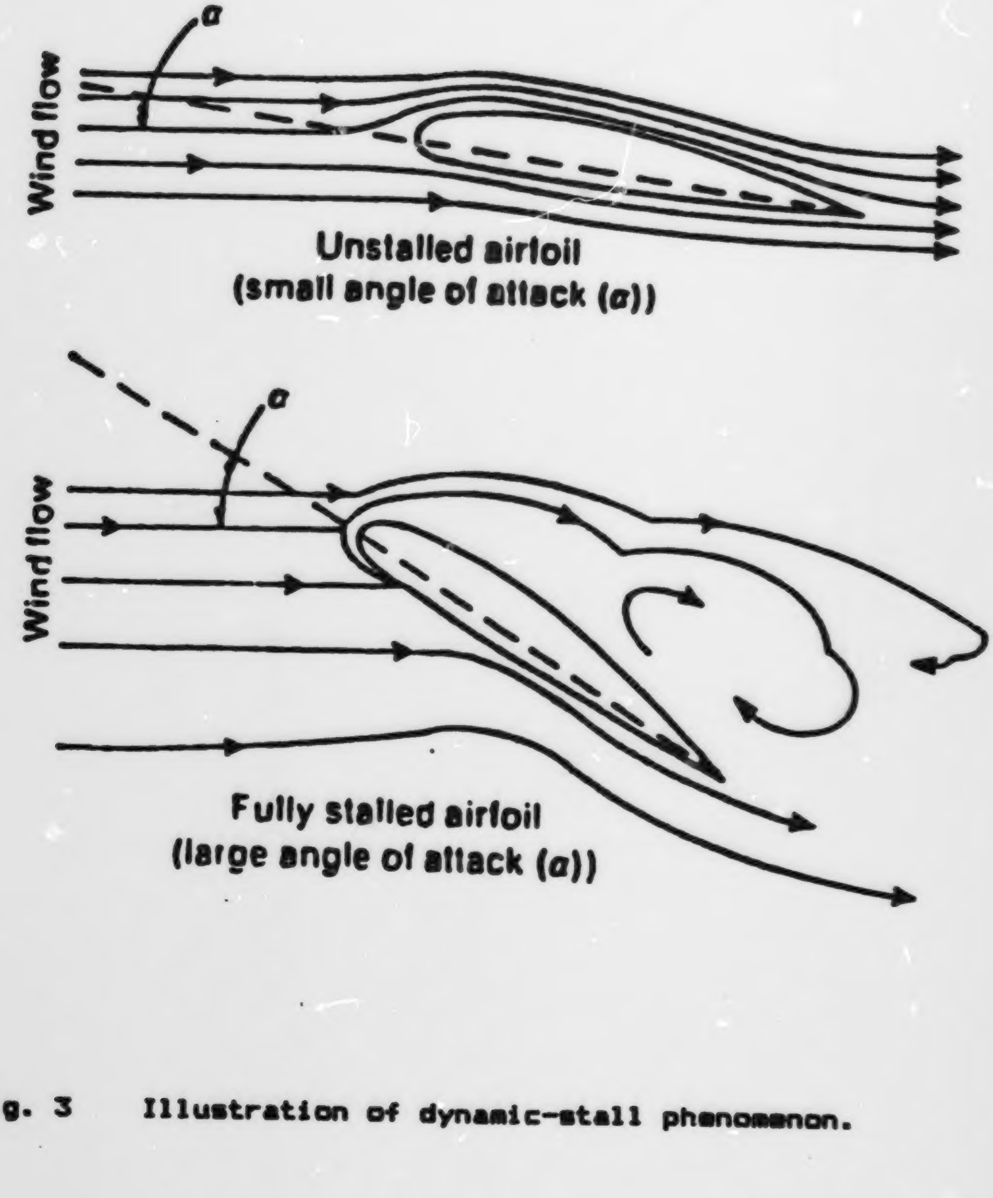

α
Wind flow
Unstalled airfoil
(small angle of attack (α))
α
Wind flow
Fully stalled airfoil
(large angle of attack (α))

Fig. 3 Illustration of dynamic-stall phenomenon.

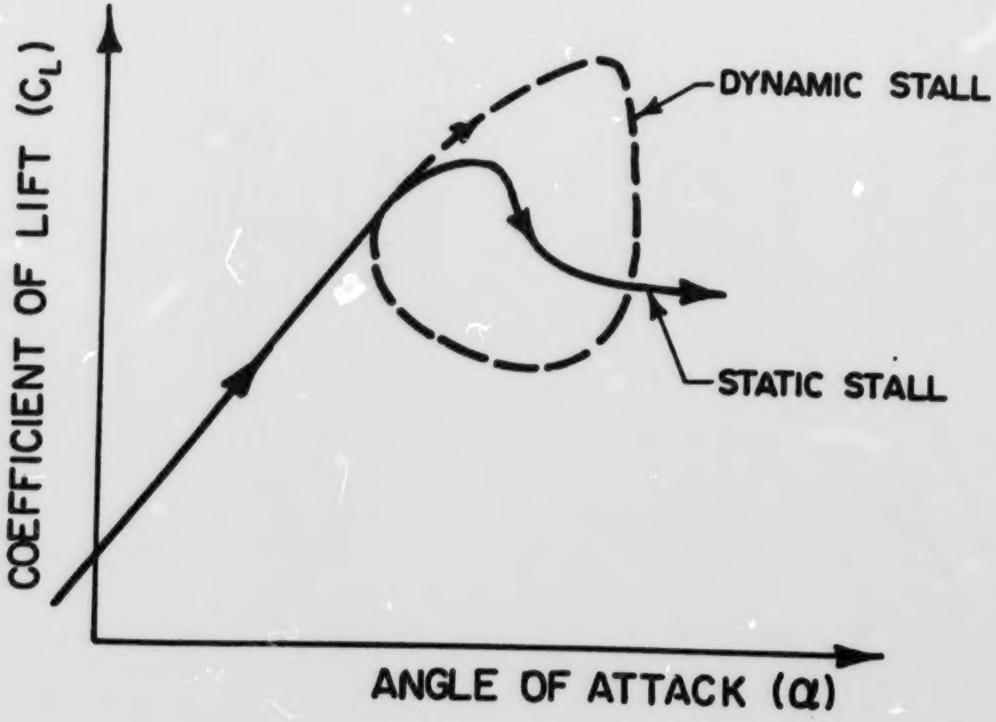
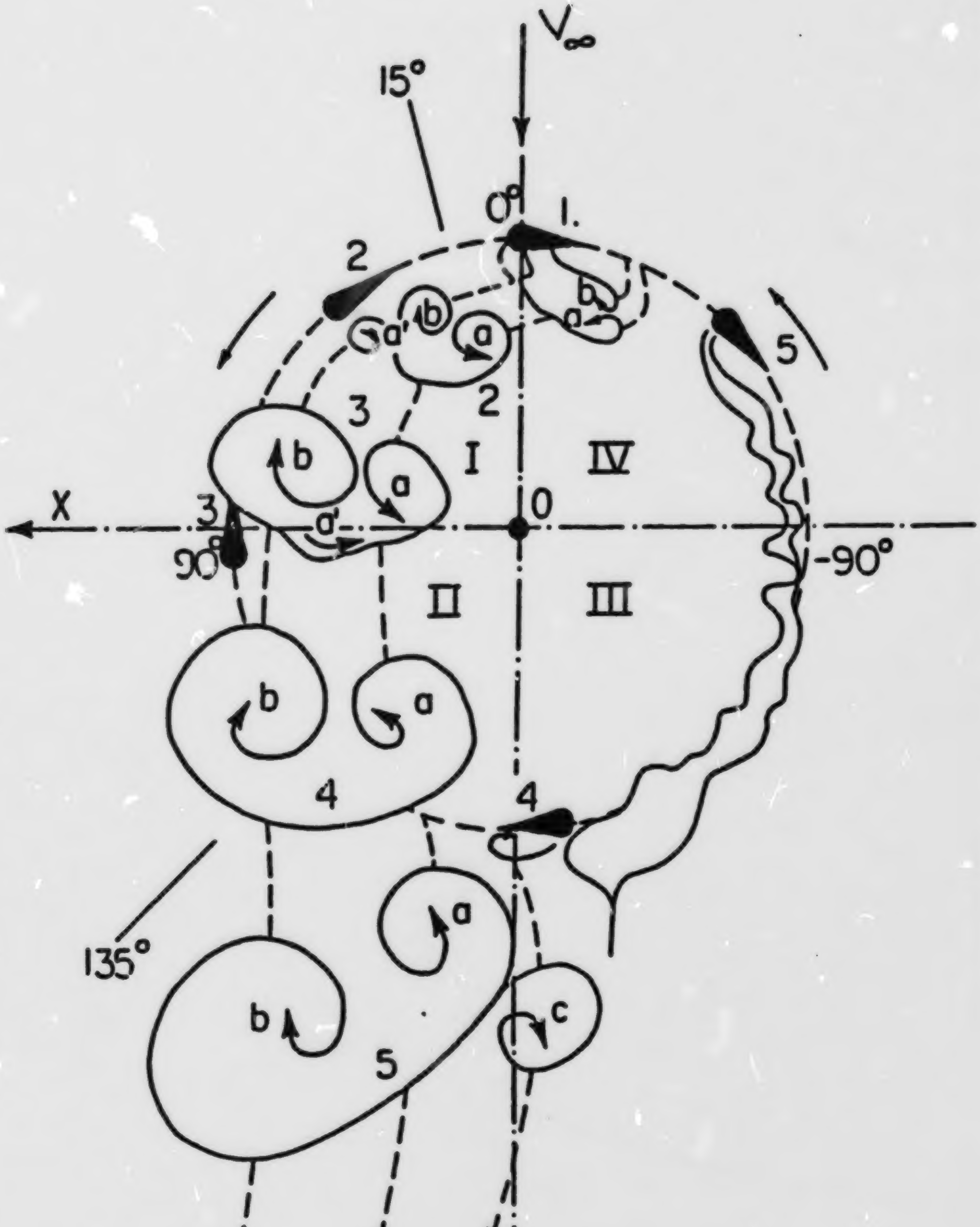


Fig. 4 Variation of lift coefficient with the nature of stall.



V∞
15°
0°
1.
2
b
a
a'
b
a
5
2
3
I
IV
b
a
X
3
0
a'
90°
-90°
II
III
b
a
4
4
135°
a
b
5
c
Y

Fig. 5 Schematic diagram of the vortex shedding for X = 2.14.

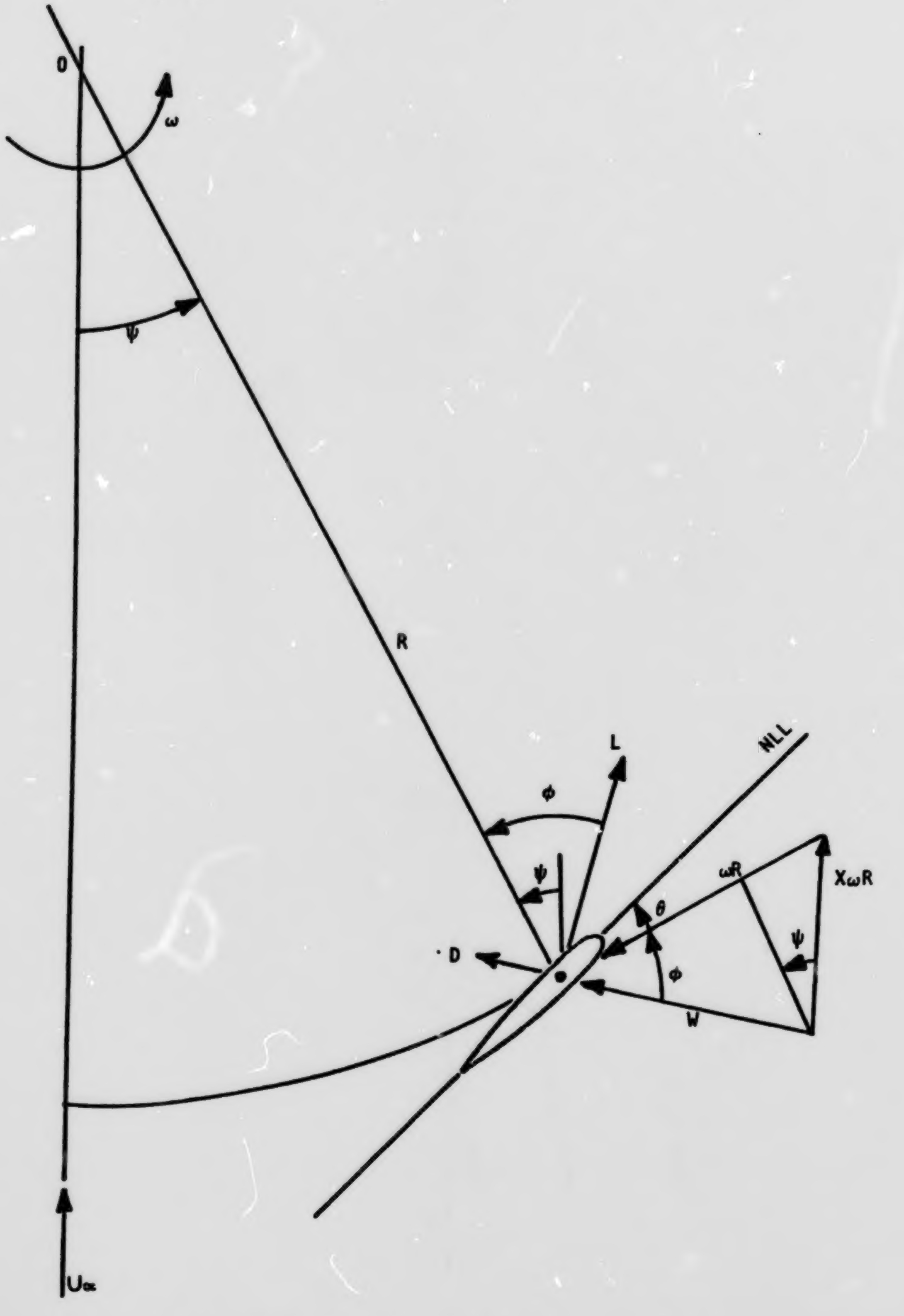

O
ω
ψ
R
L
NLL
φ
ψ
XωR
ωR
θ
ψ
D
φ
W
U∞

Fig. 6 VAWT and blade geometry. Angles, force and velocity at the equator (MIT model).

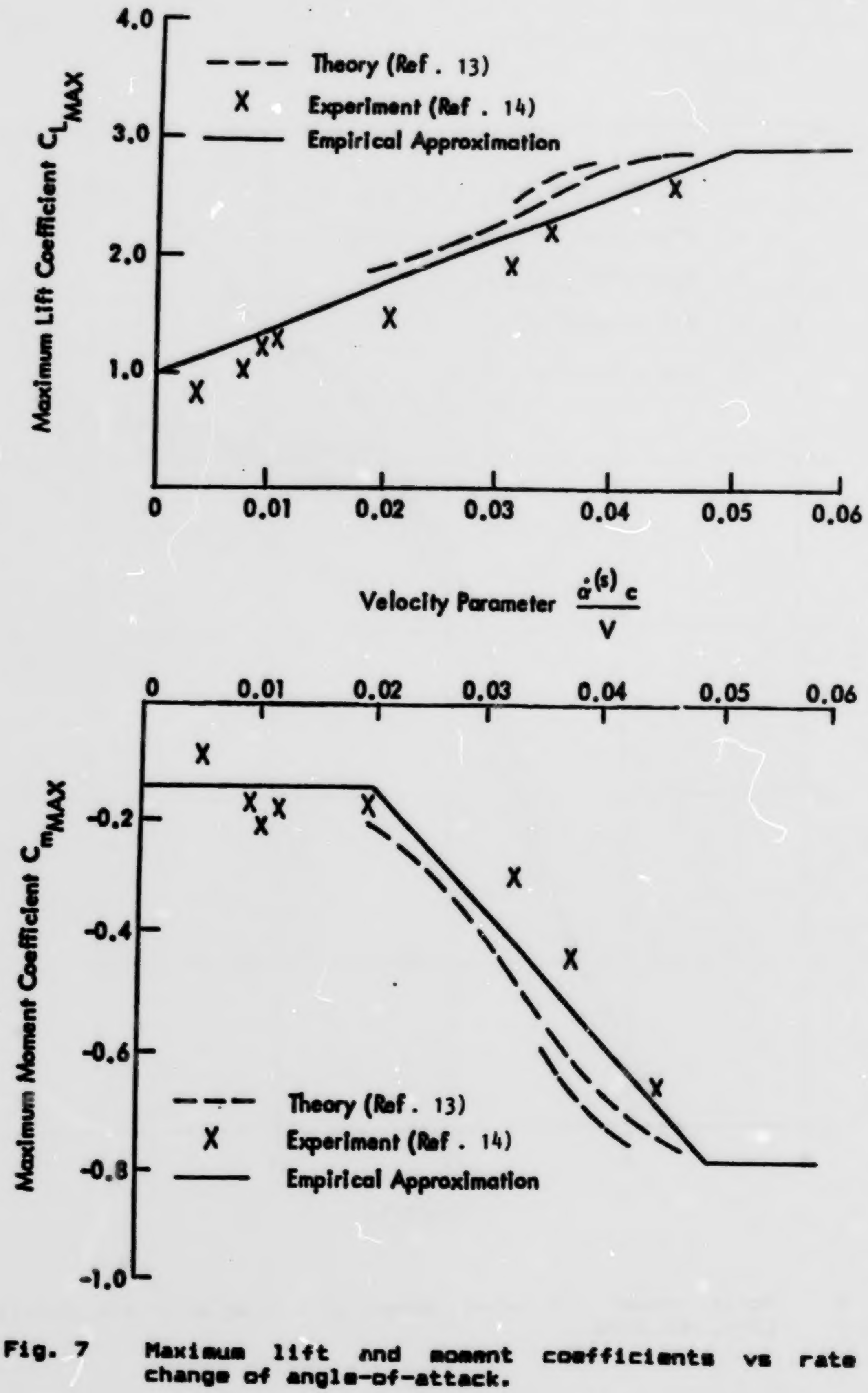


Fig. 7 Maximum lift and moment coefficients vs rate of change of angle-of-attack.

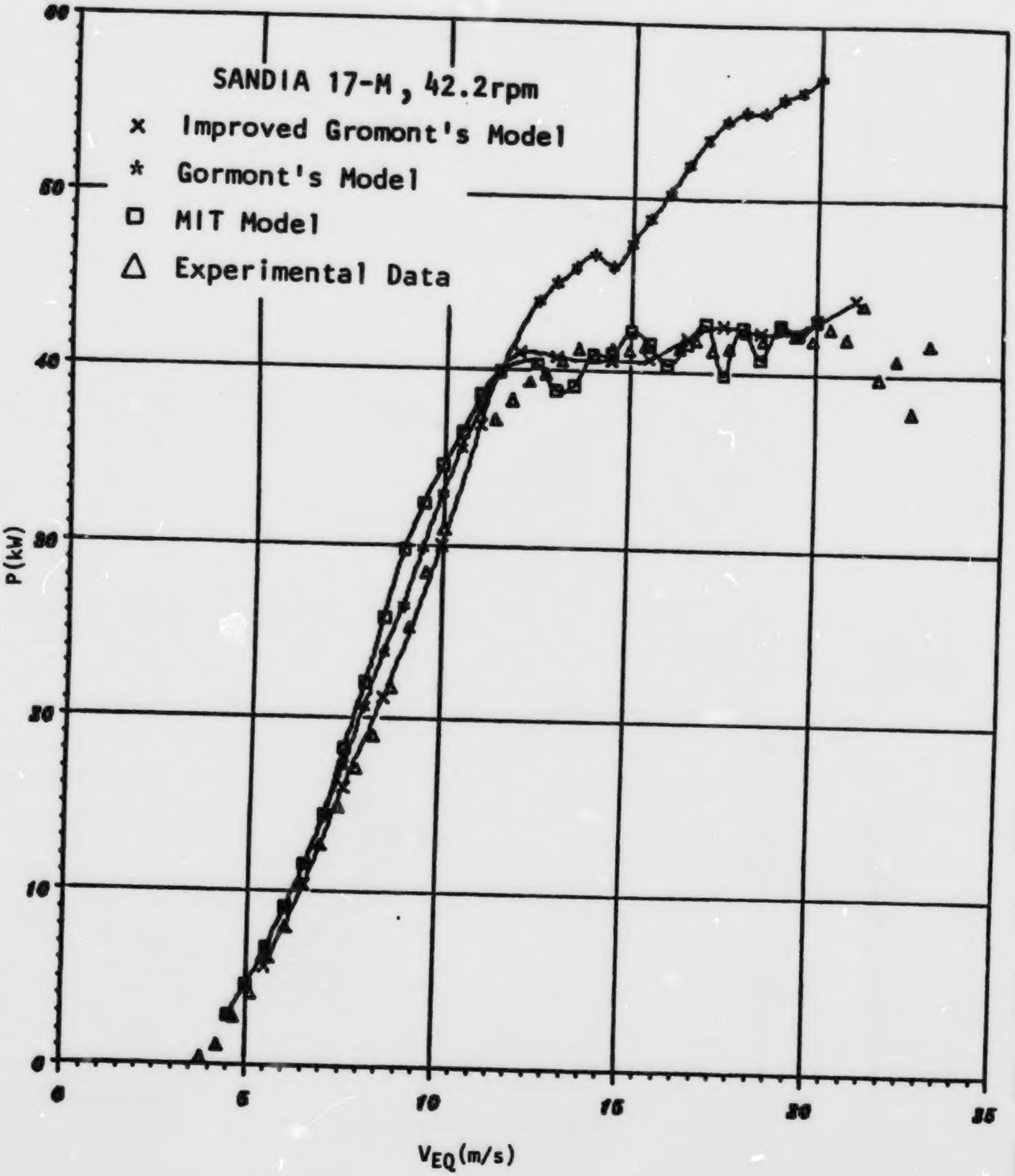


Fig. 8 Rotor power vs wind speed at the equator for Sandia 17-m, 42.2rpm.

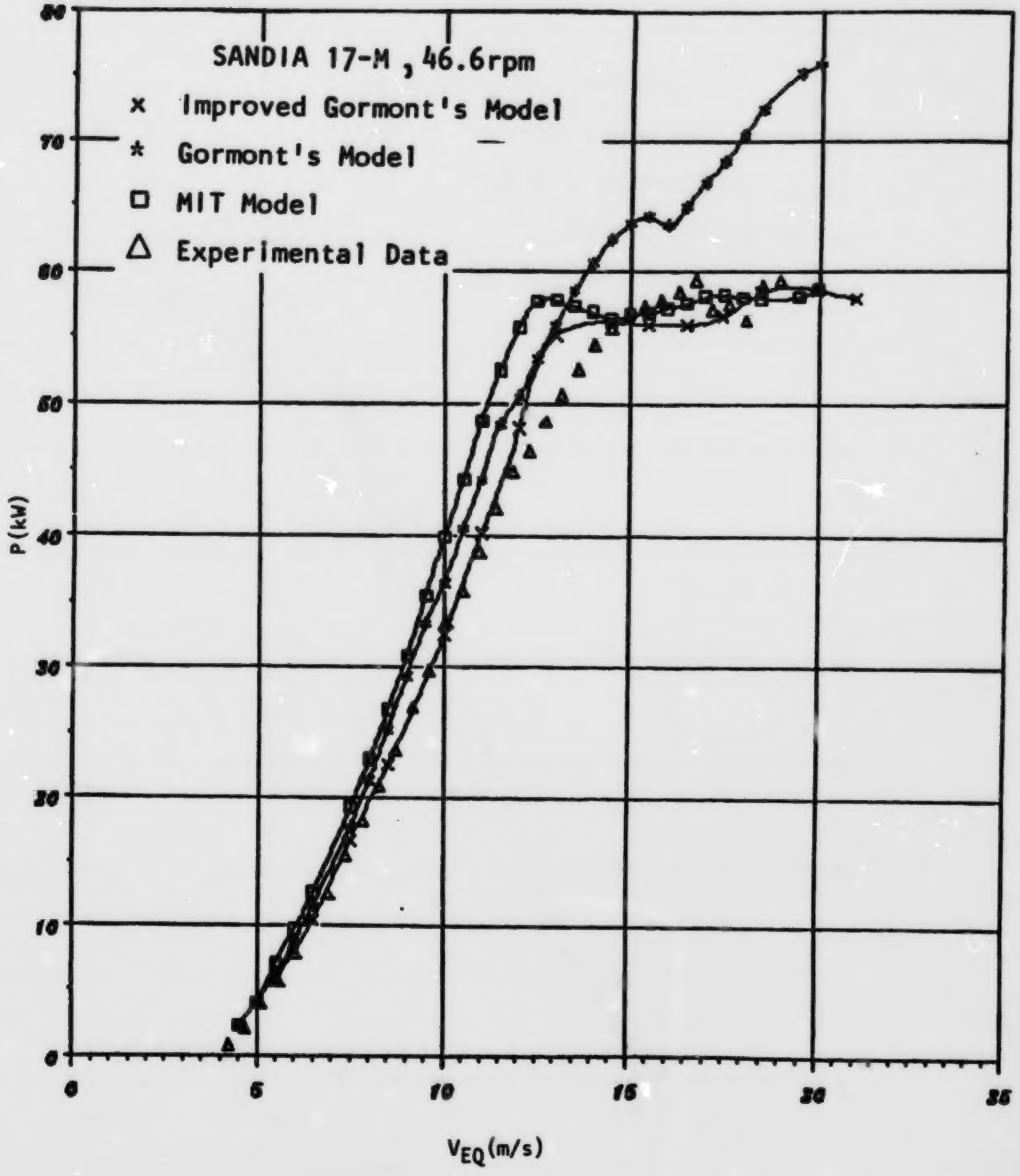


Fig. 9 Rotor power vs wind speed at the equator for Sandia 17-m, 46.6rpm.

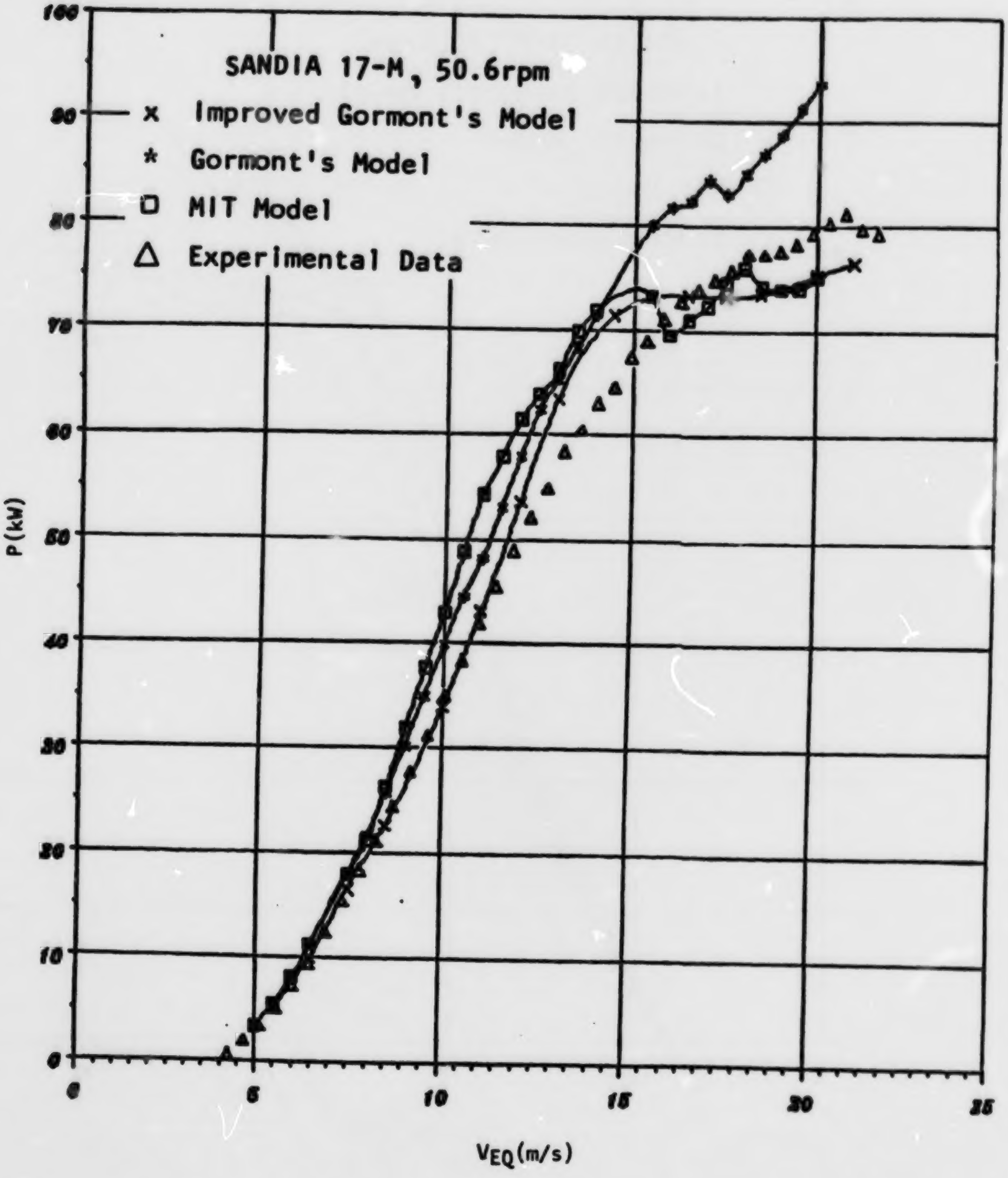


Fig. 10 Rotor power vs wind speed at the equator for Sandia 17-m, 50.6rpm.

UN MODÈLE DE SILLAGE POUR LES ÉOLIENNES DARRIEUS ET SON APPLICATION AU CALCUL DES FORCES INSTATIONNAIRES

Bernard Massé
Institut de recherche d'Hydro-Québec
1800 Montée Ste-Julie, Varennes (Québec), J0L 2P0

André Laneville et Pierre Vittecoq
Université de Sherbrooke
Sherbrooke (Québec) J1K 2R1

INTRODUCTION

La conception des éoliennes repose principalement sur le calcul des forces aérodynamiques produites par le vent qui rencontre les pales en rotation. Ces forces causent des contraintes sur la structure de la turbine éolienne ainsi qu'un couple que transmet le système d'entraînement à l'organe de conversion en puissance électrique. Plusieurs modèles de calculs ont été proposés dans le passé et leur examen par Wilson et Walker [1] donne un aperçu de leurs limitations. Les méthodes de calcul des forces aérodynamiques se divisent essentiellement en trois catégories selon qu'elles reposent sur la variation de la quantité de mouvement dans des tubes de courant [2, 3], sur la théorie tourbillonnaire [4] ou sur la méthode de la circulation locale [5, 6]. Les méthodes de tubes de courant négligent les interactions entre les tubes adjacents et n'incluent pas de modélisation du sillage et des effets instationnaires pouvant y exister. La méthode tourbillonnaire permettrait de calculer les phénomènes ponctuels instationnaires. Cependant, cette méthode nécessite un temps de calcul important et oblige souvent à utiliser une discrétisation grossière pour les cas pratiques. L'approche basée sur la méthode de la circulation locale utilise certaines simplifications qui permettent de conserver un temps de calcul assez bas tout en maintenant une modélisation suffisante au niveau des interactions dans le rotor. Cette approche devient attrayante pour les calculs en écoulement instationnaire.

Dans cet exposé, un nouveau modèle bidimensionnel de sillage est présenté pour le calcul des vitesses induites par le sillage d'une turbine Darrieus en régime instationnaire. Ce modèle est destiné à compléter le modèle de calcul des forces aérodynamiques de la référence 6 et à permettre ainsi l'inclusion des effets stochastiques du vent (turbulence) et des variations en rotation de la turbine. Après une description de l'approche utilisée, les résultats et comparaisons obtenus jusqu'à ce jour sont présentés ainsi qu'une discussion de l'application du modèle aux phénomènes instationnaires des éoliennes Darrieus.

GÉOMÉTRIE DU SILLAGE

Un des éléments responsables de la précision de la méthode tourbillonnaire est le calcul de la géométrie du sillage sous sa forme "libre", c'est-à-dire en considérant les interactions des tourbillons les uns sur les autres. Dans cette méthode, le sillage se forme petit à petit et, en régime permanent, se stabilise dans une géométrie ainsi calculée. Pour une bonne précision, le sillage est discrétisé en plusieurs points et un grand nombre de points exige un temps de calcul important.

Dans l'approche proposée ici, la géométrie est fixée de la manière suivante: un modèle de base génère des vitesses induites sur la circonférence que décrivent les pales en rotation. Ces vitesses servent à calculer les lignes d'émission des tourbillons qui s'échappent en aval pour chacune des pales ainsi que l'intensité de ces tourbillons. Une intégration est faite sur chacune de ces lignes d'émission, ce qui permet de calculer de nouvelles vitesses induites. A chaque pas de temps, la géométrie est modifiée à l'aide des vitesses induites calculées, ce qui influence l'intensité des tourbillons émis dans le sillage et réciproquement. La méthode de base servant à la première estimation des vitesses induites est décrite à la référence 6. Les hypothèses utilisées pour cette étape d'initialisation spécifient - une distribution de la circulation de forme sinusoïdale, - une infinité de pales sur la circonférence, - une vorticité libérée en ligne droite en aval et - un régime permanent. Dans ces conditions, il est possible d'évaluer des vitesses induites (réf. 6) et la géométrie du sillage, pour un nombre discret de pales, par les équations suivantes:

$$\begin{aligned} x_{s'} &= r' \cos(\theta_n - \delta) + \frac{q(\theta_n - \delta)}{r\omega} r'(\delta - \beta) \\ y_{s'} &= r' \sin(\theta_n - \delta) + \frac{v(\theta_n - \delta)}{r\omega} r'(\delta - \beta) \end{aligned} \tag{1}$$

$n = 1, 2, 3 \ldots$ nb. pales

Les principaux paramètres sont définis à la figure 1; $q(\theta_n - \delta)$ et $v(\theta_n - \delta)$ sont les vitesses de l'écoulement à la position de l'émission des tourbillons du sillage. On considère que les tourbillons conservent ces vitesses à mesure qu'ils se déplacent en aval sans être influencés par les tourbillons adjacents. Cette géométrie est recalculée à chaque pas de temps en utilisant les vitesses et les intensités des tourbillons des temps antérieurs.

Pour cette raison notre approche en est une d'évaluation numérique temporelle. La géométrie du sillage est fixée pour un temps donné mais libre de se déformer à l'instant suivant, cette déformation tenant compte des conditions aux instants précédents. Le temps de calcul se trouve ainsi réduit de façon importante au prix d'une légère perte de précision. De plus, pour un vent donné, la solution est obtenue sans aucune itération.

VITESSES INDUITES

La circulation sur la pale est fonction de la position angulaire du rotor et la variation de la circulation, $d\Gamma$, pendant un changement de position angulaire, exige qu'un tourbillon d'intensité $- d\Gamma$ quitte la pale à cet endroit et suive l'écoulement général. Ces tourbillons du sillage se distribuent selon la géométrie décrite à la section précédente et la distribution de leur intensité peut s'écrire sous la forme suivante:

$$\gamma(\theta_n - \delta) = \frac{- r d(\theta_n - \delta)}{d\ell} \frac{\partial\Gamma(\theta_n - \delta)}{\partial(\theta_n - \delta)} d(\theta_n - \delta) \qquad (2)$$

$n = 1, 2, 3 \ldots$ nb. pales

où dℓ est un élément de longueur de la ligne d'émission. Le rotor et le sillage sont couplés par cette équation et les variations de la circulation autour des pales génèrent un sillage qui influence à son tour la circulation au niveau des pales. Cette dernière influence est calculée par intégration sur les lignes d'émission pour obtenir les vitesses induites,

$$\vec{v} = \frac{1}{2\Pi} \sum_{n=1}^{\text{nb. pales}} \int_0^\infty \frac{\gamma(\theta_n - \delta)}{d} \, , \qquad (3)$$

où d est la distance entre les tourbillons et le point où l'influence est calculée sur le rotor. Cette intégration est répétée autant de fois qu'il y a de pales donc de lignes d'émission et l'effet du sillage de chacune des pales est ainsi superposé.

Ce modèle permet aussi de considérer les interactions locales d'une pale qui coupe son propre sillage et le sillage des autres pales. L'utilisation de la loi de Biot-Savart (éq. 3) pose une difficulté puisque la distance d tend alors vers zéro et la vitesse induite est théoriquement infinie. Les mesures expérimentales montrent plutôt que la vitesse est nulle pour $d = 0$ et se rapproche de la loi de Biot-Savart à une certaine distance du tourbillon. Un modèle de noyau est alors utilisé dans lequel l'intensité du tourbillon est modulée par un facteur γ_c exprimé par,

$$\gamma_c(\rho) = \frac{\rho^2}{1 + \rho^2} \quad \text{où} \quad \rho = \frac{r}{\rho_c} \, , \qquad (4)$$

où ρ_c est un rayon critique qui définit le noyau à l'intérieur duquel la vitesse induite varie de zéro sur le tourbillon même à la moitié de la valeur calculée par l'équation 3 à la limite du noyau. L'effet d'atténuation se poursuit à l'extérieur du noyau et, très loin de celui-ci, γ_c tend vers l'unité donc vers la loi de Biot-Savart. Le rayon ρ_c du noyau est déterminé à partir d'essais expérimentaux.

RÉSULTATS ET DISCUSSIONS

Ce modèle de sillage a été programmé sur ordinateur et une série de calculs a permis de vérifier la géométrie du sillage et les vitesses induites. La figure 2 compare pour une condition donnée le sillage d'une pale tel que calculé par ce modèle (en trait plein) à celui du modèle tourbillonnaire [4] (en pointillé). On constate que l'aspect général, surtout près du rotor est bien représenté. Puisque le modèle proposé néglige les influences des tourbillons les uns sur les autres à l'intérieur du sillage, la forme obtenue diffère légèrement de celle calculée avec la méthode de la référence 4. Cette perte de précision au niveau de la géométrie permet un calcul très rapide et, puisque la partie du sillage près du rotor est suffisamment bien représentée, la précision obtenue permet de croire que l'effet du sillage sera calculé avec une précision acceptable.

La figure 3 compare l'angle d'attaque calculé avec notre modèle de sillage à celui du modèle tourbillonnaire pour un rapport de vitesse périphérique à la vitesse du vent de 5. La figure 4 montre la vitesse relative pour la même condition. Dans les deux cas, l'accord est bon et indique que notre modèle est suffisamment précis pour le calcul du sillage.

La comparaison qui précède constitue une vérification du modèle dans un régime permanent i.e. un régime où la vitesse de rotation de l'éolienne et la vitesse du vent ne varient pas. Notre modèle a été étendu pour le calcul des conditions instationnaires. Afin d'étudier le comportement de notre algorithme de calcul, un départ d'éolienne a été simulé. La figure 5 illustre les changements de géométrie. Il est à souligner que l'éolienne est totalement démarrée après 5 tours, mais que le sillage prend plusieurs tours additionnels avant de se stabiliser et d'atteindre un état permanent. Ce comportement était prévu et notre modèle semble bien représenter le phénomène. Ce délai est observé aux figures 6 et 7 pour les vitesses induites sur la circonférence. Ces figures montrent également que le modèle qui recalcule la géométrie et les vitesses induites à chaque pas de temps se stabilise bien au bout d'un certain temps en régime permanent.

Le modèle de sillage tel que présenté est actuellement en voie d'être introduit dans le modèle de circulation locale de la référence 6. Ceci constituera alors un modèle pour le calcul des forces instationnaires des éoliennes Darrieus. Un tel modèle permettra de calculer les forces en régime transitoire et de tenir compte de l'aspect fluctuant du vent. Les calculs de structure et notamment les calculs en fatigue seront alors grandement améliorés.

REMERCIEMENTS

Les auteurs tiennent à remercier l'I.R.E.Q. et le C.R.S.N.G. pour leur support dans ce projet de recherche, de même qu'à Mme V. Mertens et M. R. Joubert pour les travaux de dactylographie et de dessin.

BIBLIOGRAPHIE

[1] Wilson, R.E. and S.N. Walker, The State-of-the Art in Wind Turbine Aerodynamics, Windpower 85, San Francisco, August 27-30, 1985.

[2] Templin, R.J., Aerodynamic Performance Theory for the NRC Vertical-Axis Wind Turbine, National Research Council of Canada, LTR-160, June 1974.

[3] Paraschivoiu, I., Double-Multiple Streamtube Model for Darrieus WT's, Paper presented at 2nd DOE/NASA Workshop, Cleveland, Ohio, Feb. 1981.

[4] Strickland, J.H., A Vortex Model of the Darrieus Turbine: An Analytical and Experimental Study, Sandia Laboratory, Rept. SAND 79-7058, Feb. 1980.

[5] Azuma, A. and S. Kimura, A Method of Calculation on the Airloading of Vertical-Axis Wind Turbines, Proceedings of the 18th Intersociety Energy Conversion Engineering Conference, Orlando, Fl., Aug. 1983.

[6] Massé, B., A Local-Circulation Model for Darrieus Vertical-Axis Wind Turbines, Journal of Propulsion and Power, AIAA, Vol. 2, No. 2, March-April 1986.

NOMENCLATURE

c = corde de la pale

K = constante du profil liant le bord de fuite au centre de tangage de la pale

ℓ = longueur de la trace (streakline) des tourbillons émis au bord de fuite

r = position radiale du point d'attache

r' = position radiale du bord de fuite de la pale

u = composante axiale de $\vec{v}$

v = composante transversale de $\vec{v}$

$\vec{v}$ = vitesse induite

V = vitesse du vent en amont

x_s = abcisse de la trace des tourbillons

y_s = ordonnée de la trace des tourbillons

β = angle entre r et r'

$\delta - \beta$ = angle parcouru par la pale durant un temps donné

γ = intensité des tourbillons

Γ = circulation

θ_n = position angulaire de la pale n

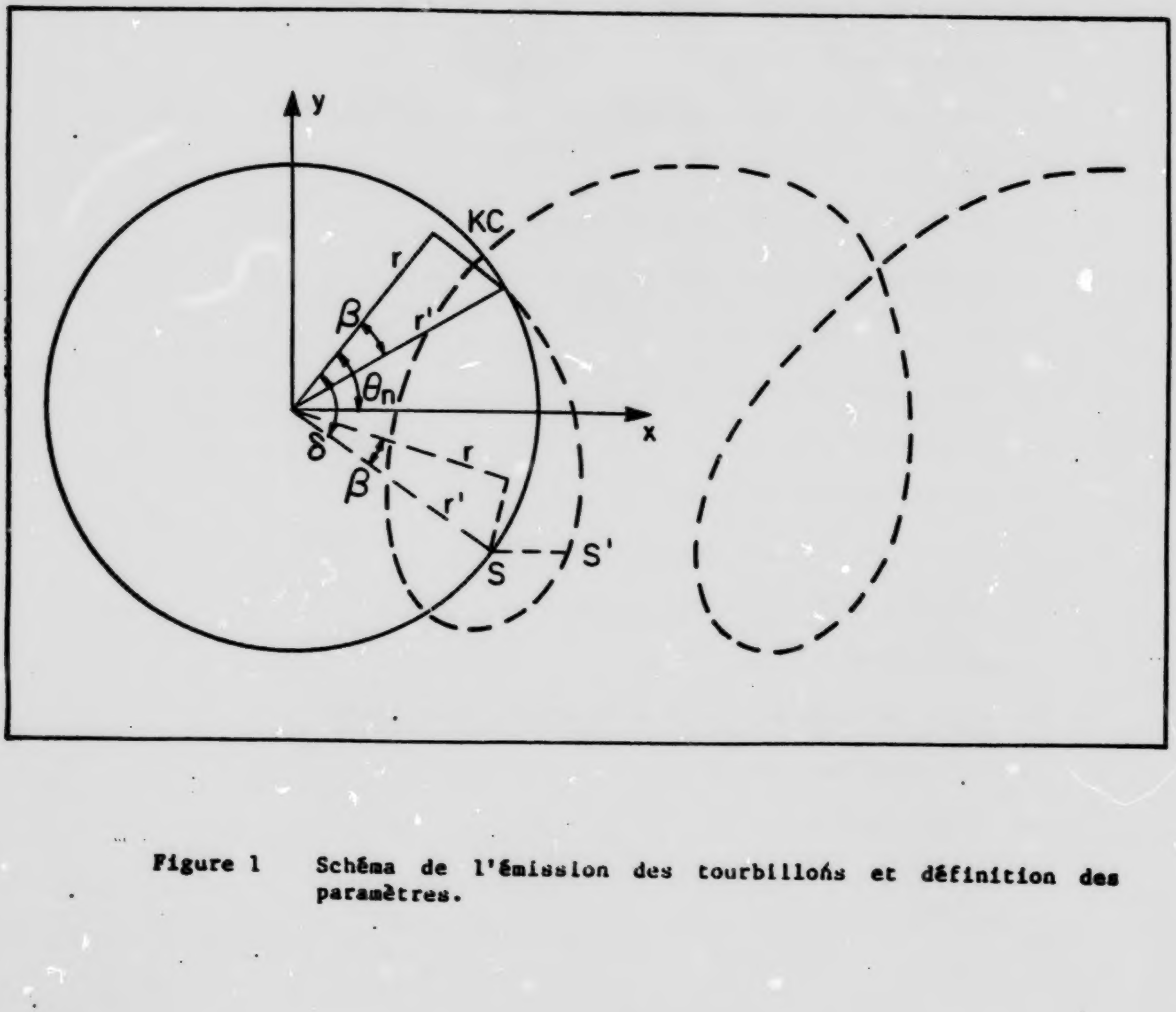

y
KC
r
β
r'
θ_n
x
δ
β
r
r'
S
S'

Figure 1 Schéma de l'émission des tourbillons et définition des paramètres.

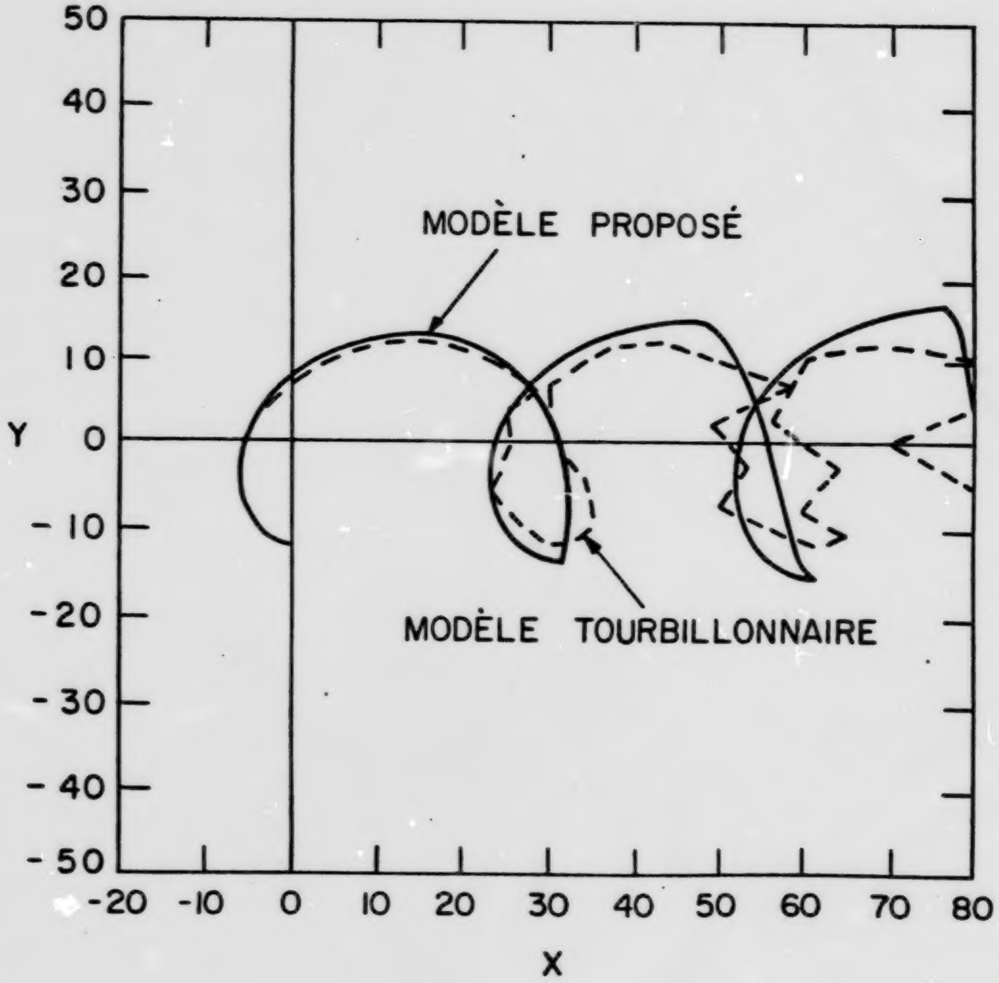


Figure 2 Comparaison de géométrie des sillages pour les modèles. (unités: mètres, r = 12.2 mètres).

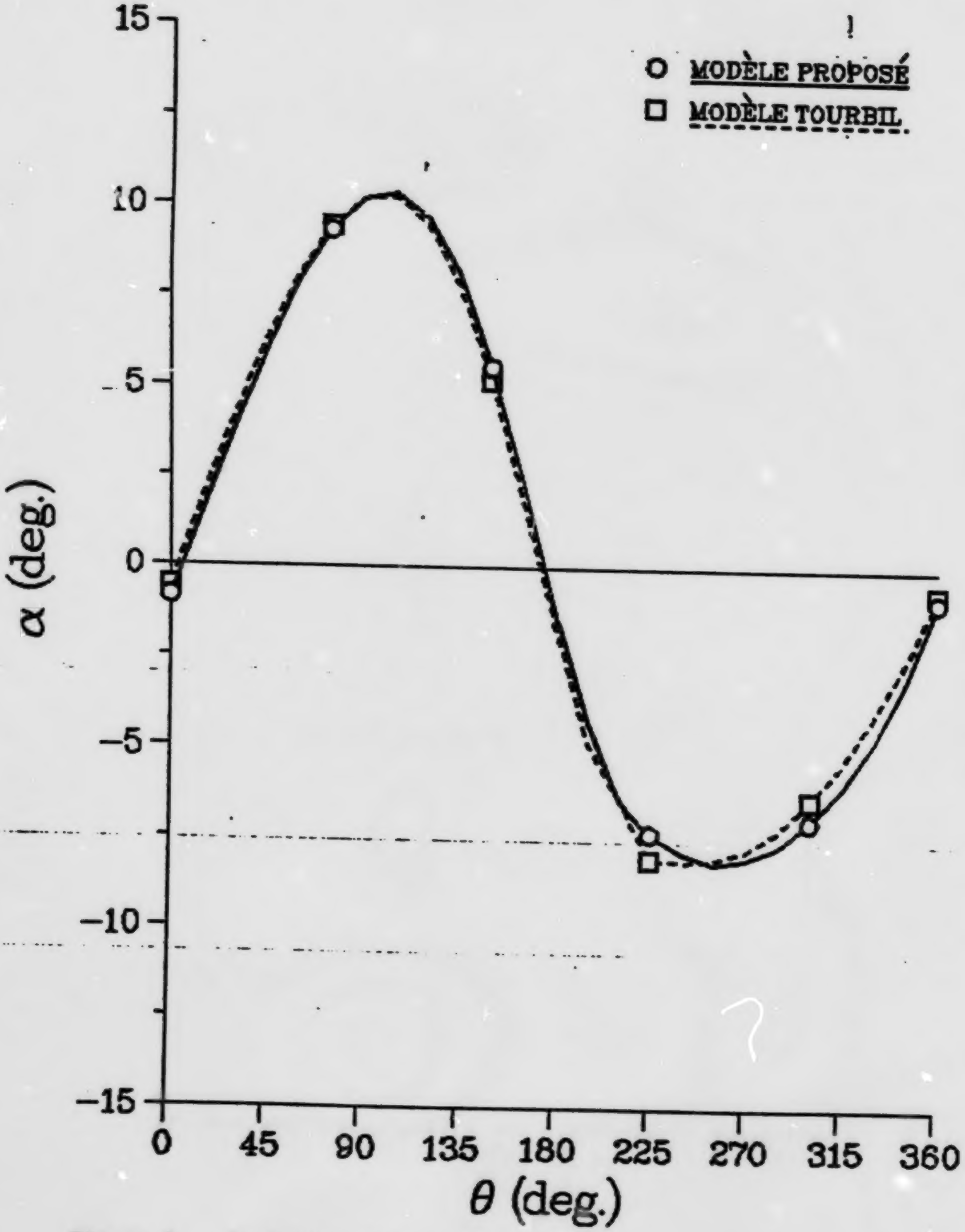


Figure 3 Evolution des angles d'attaque en fonction de l'azimuth pour les deux modèles (amont 0 < θ < 180°, aval 180° < θ < 360°).

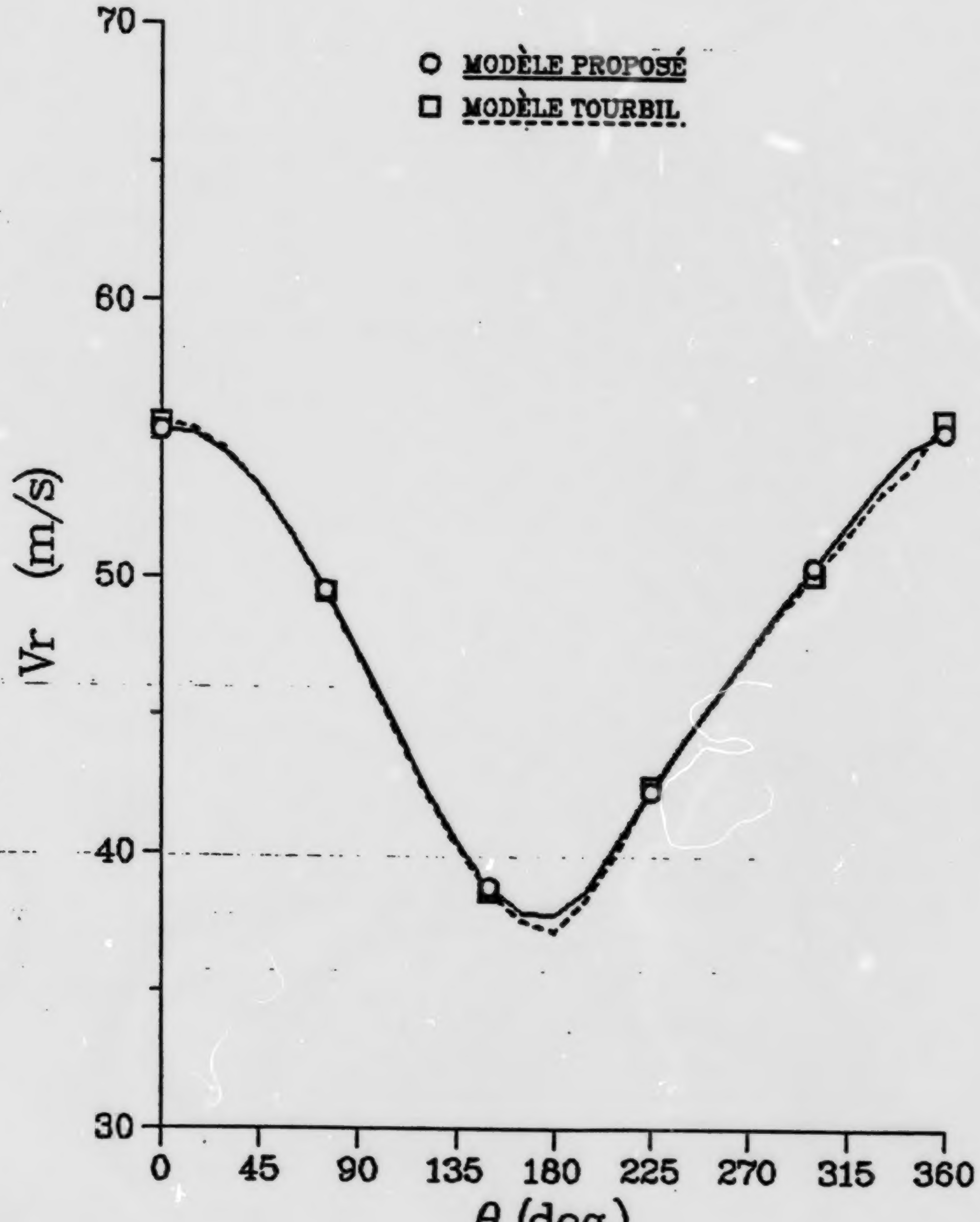


Figure 4 Evolution des vitesses relatives en fonction de l'azimuth pour les deux modèles (amont $0 < \theta < 180°$, aval $180° < \theta < 360°$).

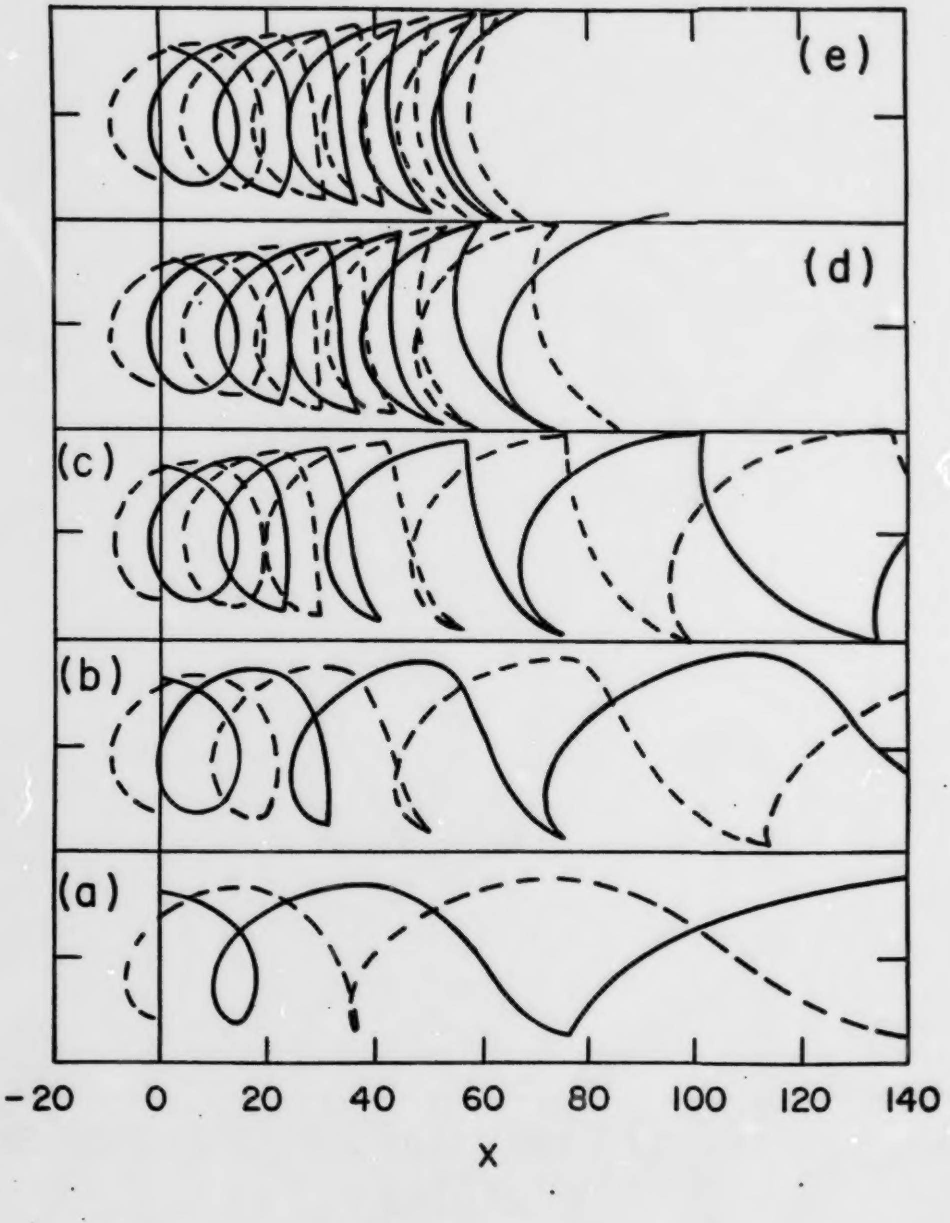


Figure 5 Evolution du sillage pour une mise en marche [a) après 3 tours; b) après 5 tours; c) après 7 tours; d) après 9 tours; e) après 11 tours], (unités: mètres, r = 12,2 mètres).

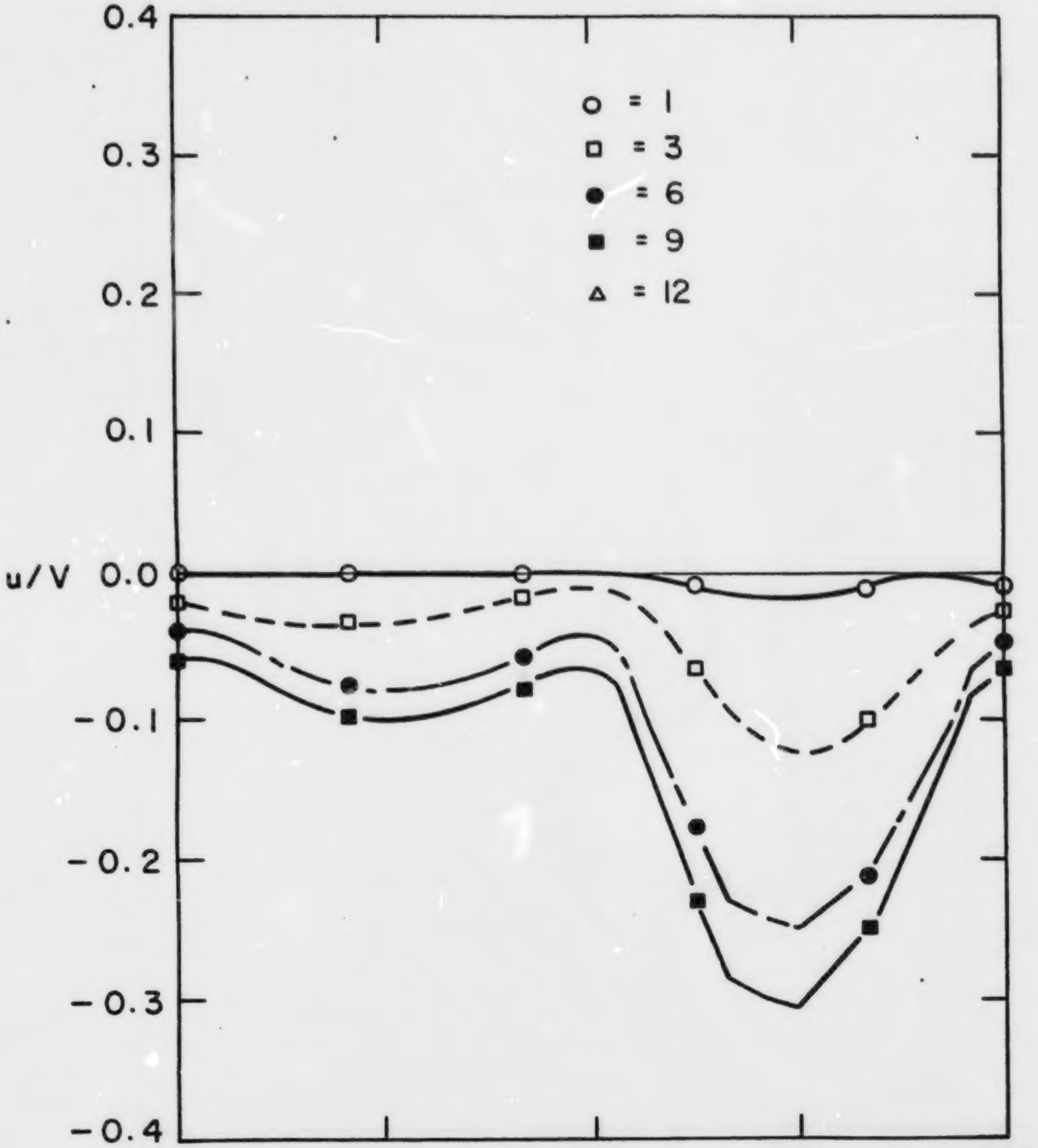


Figure 6 Evolution des vitesses axiales induites par le sillage sur le rotor en fonction de l'azimuth après 1, 3, 6, 9 et 12 tours (9 et 12 superposés) (amont 0° < θ < 180°, aval 180° < θ < 360°)

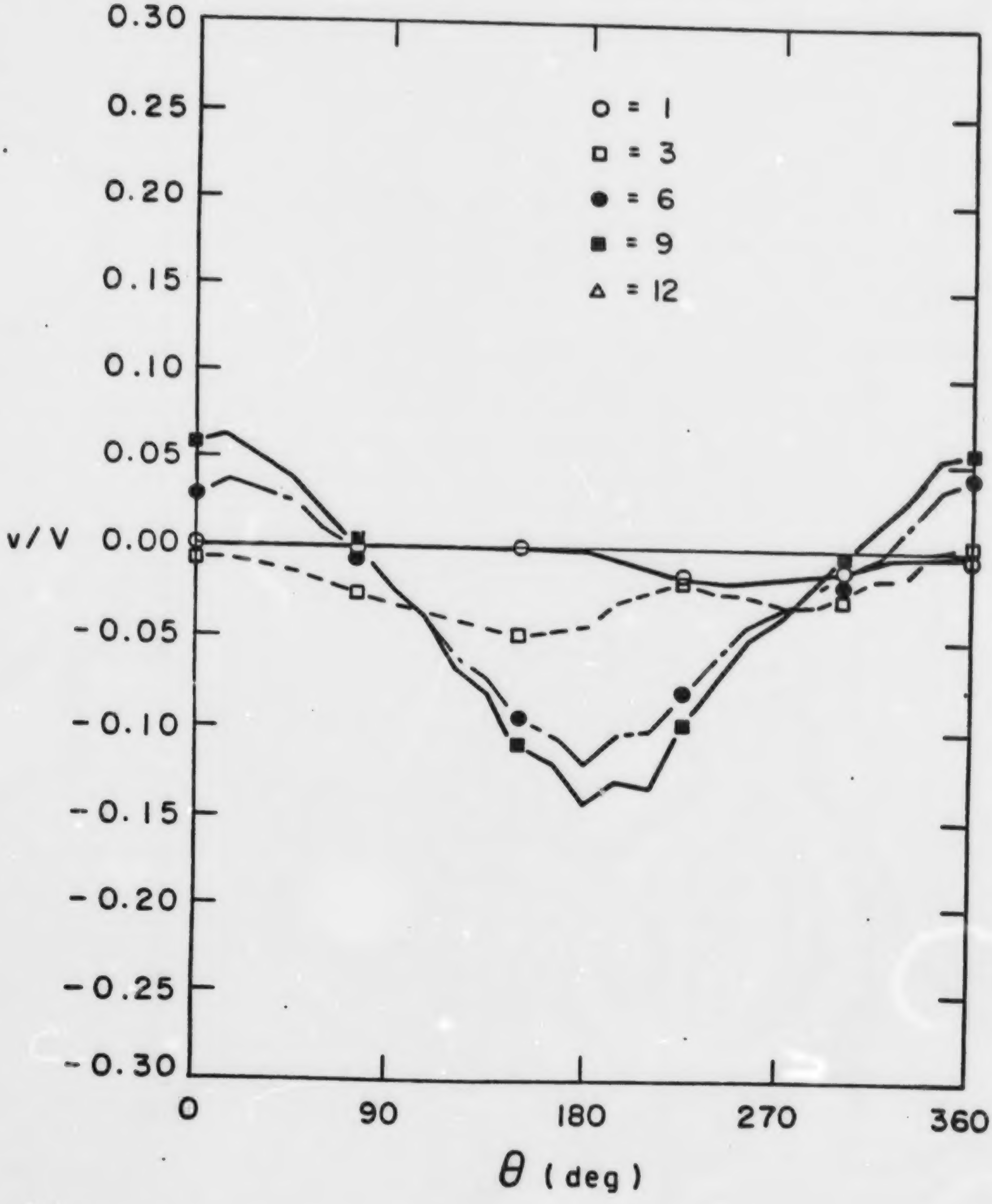


Figure 7 Evolution des vitesses transversales induites par le sillage sur le rotor en fonction de l'azimuth après 1, 3, 6, 9 et 12 tours (9 et 12 superposés) (amont 0° < θ < 180°, aval 180° < θ < 360°)

DESIGN OF GEAR-LESS WIND TURBINE VARIABLE SPEED GENERATORS

J. Hylander[*], S. von Zweygbergk[*], S. Engström[**]
Ph.D. Professor M.Sc.

ABSTRACT

If the use of gear boxes in grid connected wind turbines could be eliminated with convertor connected low speed generators, a reduction of cost and weight of the plant could be possible. Studies of these generators have been performed within the Swedish wind energy research programme.

Earlier designs of gearless low speed generators have often had fixed speed operation with the stator connected directly to the grid. The generator volume will then be much larger than the volume of a generator with a gear box, as the volume is approximately proportional to the rated torque. However, if the generator is connected to a convertor in order to allow variable speed operation, it will be possible to use frequencies higher than the grid frequency. With higher frequency the magnetic flux in the generator will be reduced, which makes it possible to design the machine with less iron. This will reduce the weight and cost of the generators.

The design results from this study of low speed synchronous and induction generators in the rated range of 200 ... 4000 kW are presented in this paper together with comparative designs of standard machines.

INTRODUCTION

Large wind power units are usually eqippped with a two or three step gear, connected between the wind turbine and the generator. Such a gear is heavy and expensive, and it sensitive to vibrations and sudden changes of the torque due to wind gusts.

It is in principle possible to eliminate the gear by connecting the wind turbine directly to the generator, eventually in an integrated design, where the generator rotor constitutes a part of the wind turbine. The speed of such a gearless generator, however, is low because the tip speed of the wind turbine for mechanical strain reasons cannot exceed a certain value of about 100 m/s.

---

[*] Department o Electrical Machines and Power Electronics
Chalmers University of Technology
412 96 Göteborg
Sweden

[**] National Energy Administration (STEV)
Box 9049
102 71 Stockholm
Sweden

As will be shown below, this fact leads to the results that the diameter of the generator will be large and the stack length will be small. It will be shown in Appendix I that the air gap power P_δ in the generator may be expressed in the following form:

$$P_\delta = K \; B \; A \; n \; D_\delta^2 \; L \; \cos\phi \qquad (1)$$

where

K = a numerical factor
B = air gap flux density
A = linear current density
n = rated speed (rpm)
D_δ = inner diameter of the stator
L = stack length
$\cos\phi$ = power factor

If the product $B \cdot A$ is large, then the product $D_\delta^2 L$ will be small, which means that the volume and the size of the generator will also be small. The saturation value of the iron limits the flux density B, and the temperature rise in the stator winding determines a maximum value for the linear current density A. If the rated speed of the generator is low, then the product $B \cdot A$ also will be low and the product $D_\delta \cdot L$ will be high. If the stack length L is large, then the temperature rise of the stator and rotor surfaces in the air gap will be high, if natural cooling is used. Consequently as L cannot exceed a certain value, the diameter D_δ must increase when the power is increased. This is the reason the diameter of a generator in a large wind power unit will be large and the stack length will be small.

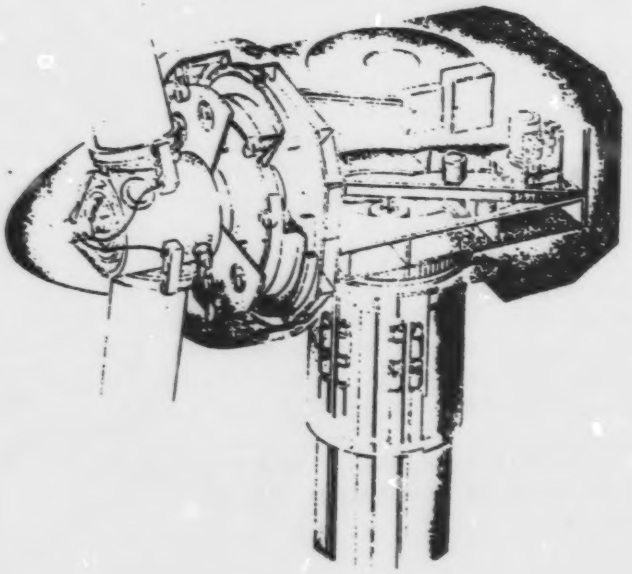


Figure 1: A direct driven generator.

Calculations of gearless wind generators have earlier been performed in Sweden (Ref.[1]). In this case the subject of the investigation has been generators connected to the utility grid. In the mentioned paper a detailed analysis of a 2.5 MW gearless synchronous generator has been carried out. The pole number of this generator was 216, the speed 28 rpm, the diameter of the stator 7 meters and the weight of the active material 12 tons. The generator is integrated with the wind turbine and the rotor bearings are fixed to the stator.

A wind power unit equipped with such a generator is compared with a unit equipped with a gear and a conventional generator. The comparison gives the following results:

	WEC with gearless generator	WEC with gear and conventional generator
weight	428 ton	461 ton
price (1981)	$1.7\ 10^6$ $ (US)	$1.92\ 10^6$ $ (US)
energy/year	6.18 GWh	6.07 GWh

The produced yearly energy is calculated based on the prevailing wind conditions at the large wind power unit in Maglarp, Skåne.

The present paper deals with gearless generators connected to the grid by means of converters and DC-links. In such a system the frequency as well as the voltage may be freely chosen within certain limits.

The principal aim of the investigation is to establish the main dimensions for gearless generators, where the frequency and the voltage have been determined in order to achieve an optimal construction with regard to efficiency, cost and weight.

The investigation deals with synchronous as well as induction generators.

THE FUNDAMENTAL IDEA OF THE DESIGN

Earlier, cycloconvertor connected synchronous machines have been used in some applications (Ref.[2]). These machines operate at low frequency and speed. The volume and weight of these machines however makes them not attractive in some wind converter applications. The reasons are as before: the rated output power is proportional to speed and air gap volume (Equ.(1)).

If for an arbitary electrical machine, the grid frequency, (f) is increased by connecting a convertor between the grid and the generator, the power is increased as the synchronous speed is proportional to the frequency and the number of pole pairs (p):

$$n_s = \frac{60\ f}{p} \qquad \text{(rpm)} \qquad (2)$$

However, if the the synchronous speed should be constant, the number of poles must increase. This reduces the magnetic air gap flux in the machine, which is proportional to the air gap flux density (B_δ), the length (L), the pole arc coefficient (α) and the pole pitch (τ_p):

$$\tau_p = D_\delta \frac{\pi}{2p} \qquad (3)$$

$$\Phi_\delta = B_\delta \, \alpha \, L \, \tau_p \qquad (4)$$

The airgap flux in the machine determines the outer diameter (D_o), as this flux must pass through the iron stator core. The necessary area of the stator core (A_c) with the maximum permitted flux density in the core (B_c) is:

$$A_c = \frac{\Phi_\delta}{2 \, B_c} \qquad (5)$$

If the flux is reduced, the necessary area of the stator core can be reduced. This gives a reduction of iron weight compared to a low frequency generator at the same synchronous speed and air gap volume.

With this approach the slot pitch (τ_s) will become smaller and smaller as the number of slots increases with the increase in poles. The total slot number in the stator is:

$$Q = m \, q \, 2 \, p \qquad (6)$$

where q is the number of slots per pole and phase, and m the number of phases.

A method more suitable for manufacturing purposes is to have the slot pitch at a fixed value, which increases the diameter and reduces the length of the machine instead of the height of the stator core.

In order to give the necessary space for the slots in the machine, the slot pitch has a minimum value. If the slot pitch is kept at a constant minimum value, the air gap diameter of the machine will increase:

$$D_\delta = \frac{\tau_s \, Q}{\pi} \qquad (7)$$

With Equ.(1) the necessary length can now be determined. As the diameter is proportional to the frequency, the iron length will be inversely proportional to the square of the frequency (if the synchronous speed is kept constant).

In this case there will be no reduction of the stator core height, as the length of the machine is already reduced sufficiently, and the pole pich is constant. The stator weight reduction is achieved by the reduced length. The volume of the stator iron is:

$$V = \frac{\pi}{4} \left(D_o^2 - D_\delta^2 \right) L - Q \, A_{slot} \, L \qquad (8)$$

where D_o is the outer diameter. As the stator core and the slot-height are not changing as the flux is reduced in relation to the length reduction, and the rated current density and the phase current are still the same, the outer diameter can be expressed as:

$$D_o = D_\delta + 2\ h \tag{9}$$

where h is the sum of the stator core and slot height.

The stator iron volume can now be expressed as:

$$V_{fe} = \pi\ h\ (\ h + D_\delta)\ L - Q\ A_{slot}\ L \tag{10}$$

The volume reduction if the frequency is doubled is:

$$\Delta V_{fe} = \frac{D_\delta\ L}{2}\ \pi\ h \quad + \quad Q\ A_{slot}\ L \tag{11}$$

where D_δ, L and Q here are the initial air-gap diameter, the length and the number of slots.

The changing number of stator slots and the reduced length of the generator have to be taken into account when determing the copper volume of the stator. The length of a half stator coil in one slot and its coil end is:

$$L_{cu} = L + 1.4\ \tau_p \tag{12}$$

The total copper volume can now be determined:

$$V_{cu} = Q\ A_{cu}\ (\ L + 1.4\ \tau_p) \tag{13}$$

where A_{cu} is the copper area of each slot. The copper volume reduction if the frequency is doubled is:

$$\Delta V_{cu} = Q\ A_{cu}\ (\ \frac{L}{2} - 1.4\ \tau_p) \tag{14}$$

The equation above indicates that if the length of the generator is reduced to less than 2.8 τ_p, the copper volume of the stator will increase.

If the generator is a synchronous machine, the active iron volume of the rotor can be calculated like the stator iron volume. The maximum permitted flux density in the rotor gives the necessary area of the rotor iron. The rotor can be designed in a rim form. The supporting spokes and shaft are not included as active material in this calculation.

The copper volume of the field winding is dependant on the mmf needed to magnetize the generator, which gives the number of winding turns and the length of the machine, as with the stator winding. The air gap, which here is proportional to the inner diameter of the generator, influences mmf calculations. As the air gap increases, the air gap mmf will also increase.

SYNCHRONOUS GENERATORS

A computer program was developed which performs the earlier presented calculations and the additional necessary time consuming work needed to get characteristics such as losses and electrical parameters of the low speed synchronous generator. The calculations performed follow the procedures given in Ref. [3] and [4] with slight modifications. The program was tested and debugged with good results on standard machines and the previosly investigated 50 Hz generator (Ref. [1]). The formulas used however, are not verified for very short, high frequency machines, especially with regards to leakage reactances, for which formulas are not even established. In this calculation the ordinary formulas have been used which will introduce some errors. The influence of the harmonics from the frequency convertor is also neglected. The stray losses are calculated as 0.5% of the rated power.

The results from the calculations are presented below for the three investigated generator sizes at some frequencies:

200 kW 75 rpm
1500 kW 40 rpm   50 ... 100 Hz
4000 kW 25 rpm

The electrical and magnetic loading, i.e. the flux densities and the linear current density, has been kept constant for all three sizes except for a high efficiency version of the smallest machine. The air gap in relation to the inner diameter is also constant. The flux densities and the current densities are:

$B_\delta = 0.67$ (T) flux density air gap
$B_t = 1.5$ (T) maximum flux density tooth
$B_c = 1.1$ (T) maximum flux density stator core
$B_f = 1.1$ (T) maximum flux density pole
$B_{fc} = 1.0$ (T) maximum flux density pole core
$S_s = 4.0$ (A/mm^2) current density stator
$S_f = 3.8$ (A/mm^2) current density field
$A = 67\ 825$ (A/m) linear current density

The slot pitch has been constant:

$\tau_s = 26.3$ mm

The number of slots per pole and phase has been:

$q = 1\ ^1/_8$

With the 200 kW generator the minimum weight corresponds to about 70 Hz. The weight reduction is then 8.4 % compared with a 50 Hz design. The efficiency however drops from 87.5 % to 85.9% in this case.

206 kVA cosϕ=0.97 U=400 V I=297 A n=75 rpm

f	50	70	Hz
p	40	56	-
η	87.5	85.9	%
D_o	2 390	3 294	mm
D_δ	2 257	3 160	mm
L	110	56	mm
δ	1.6	2.2	mm
G_{fe1}	372	266	kg
G_{cu1}	251	271	kg
G_{fe2}	360	287	kg
G_{cu2}	247	303	kg
ΣG	1 230	1 127	kg

As the length is shorter than 2.8 times the pole pitch, the stator copper weight increses for this particular generator.

The efficiency can be increased if the maximum flux densities and current densities are reduced. The iron and copper losses are then reduced. If the following values are used instead of those previosly presented (B_t=1.2 T, B_c=1.0 T, S_s=S_f=1.0 A/mm^2, A=22 608 A/m), the efficiency for the 200 kW generator will now increase to 94.1% at 50 Hz. The length will also naturally increase to 330 mm, which will give the generator a total weight of 4 665 kg.

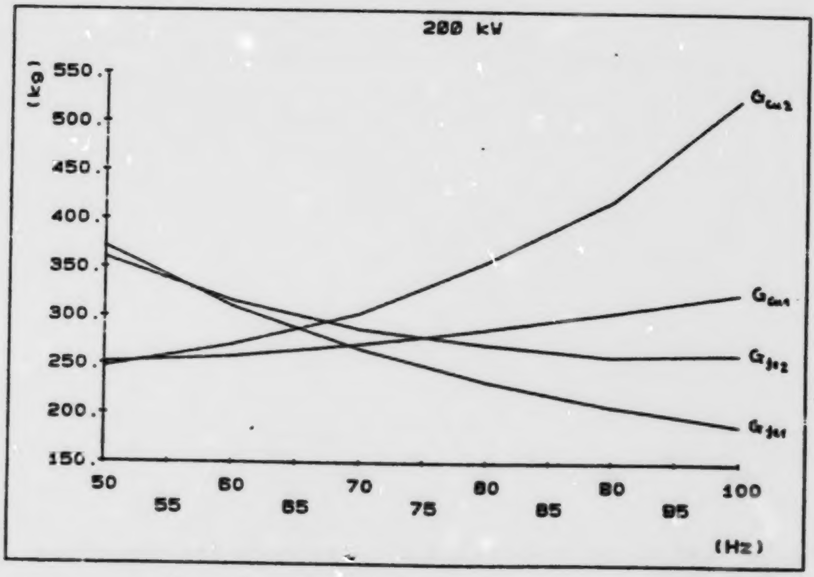


Figure 2: Weights as function of frequency for the 200 kW machine.

With a 40 rpm 1500 kW generator the efficiency increases with higher frequency and reaches its maximum of 91.5% at about 70 Hz, compared to 90.9% at 50 Hz. The weight reduction at 70 Hz is 18.9%. At 100 Hz the weight reduction is 28.8% but the efficiency is reduced to 91.0%. The outer diameter is 8.606 m at 100 Hz and the iron length is 0.11 m with the total weight of active material 5 937 kg. The air gap is 6 mm.

The largest investigated synchronous generator, the 4 000 kW machine, has its maximum efficiency of 91.5% at about 80 Hz compared to 90.6% at 50 Hz. The weight reduction is here 24.1%. At 100 Hz the weight reduction is 29.9% and the efficiency 91.3%. The outer diameter is now large at 100 Hz, 13.691 m, and the iron length is 0.183 m with the total weight of active material 16 421 kg. The air gap is 9.6 mm.

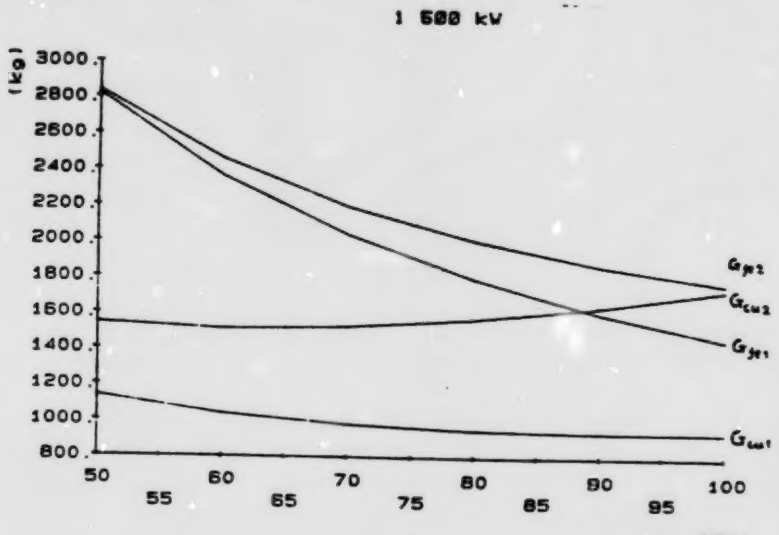


Figure 3: Weights as a function of freqency for the 1 500 kW machine.

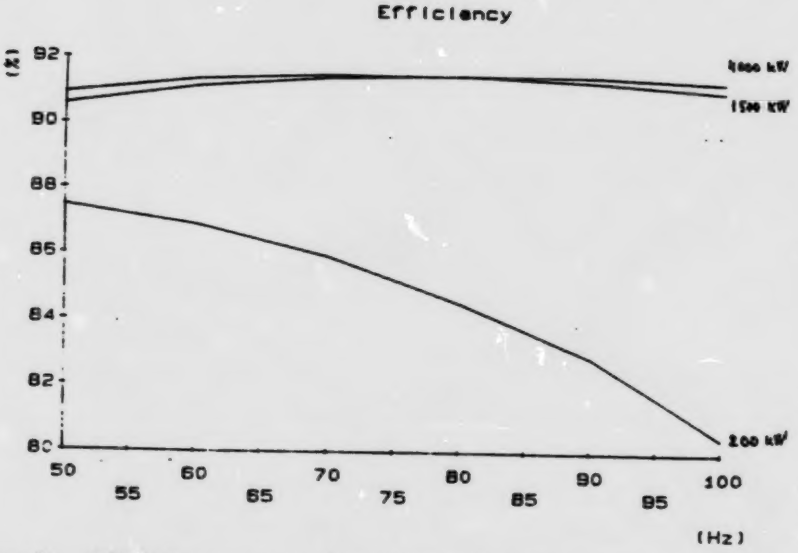


Figure 4: Efficiency as a function of frequency for the three machines.

INDUCTION GENERATORS

A generator with a large air gap diameter must for mechanical reasons have a rather large air gap. This means that the magnetizing current in an induction generator also tends to be large. In this case the generator will operate with a small power factor.

If the generator voltage is rectified by means of a diode bridge, it is necessary to connect a rather big controllable capacitor to the generator terminals in order to supply the required reactive power to the generator. By using a self commutated convertor instead of a diode bridge the capacitor can be eliminated because the reactive power can be supplied to the generator simply by controlling the firing angle of the convertor.

This means that an induction generator equipped with a self commutated convertor may have a low power factor, but this fact will not affect the operation of the generator. One must, however, take into account that a self commutated convertor is a lot more expensive than a diode bridge.

In order to achieve optimal values with regard to efficiency, weight, cost and power factor of a low speed induction generator, computer calculations have been made. Results from these calculations are given below. Calculations have been performed for two frequencies, 50 Hz and 100 Hz in order to demonstrate how the frequency affects the sizes and the qualities of the generators.

200 kW induction generator for 75 rpm

Frequency	50	100	Hz
Outer diameter of stator	2.1	4.1	m
Stack length	.6	.15	m
Air gap	1.6	3	mm
Weight of active iron	2088	1037	kg
Copper weight	975	716	kg
Efficiency	.87	.86	
Power factor	.58	.40	
Rated slip	-.085	-.065	
Maximal torque	2.1	1.7	pu

1500 kW induction generator for 40 rpm

Frequency	50	100	Hz
Outer diameter of stator	5.15	10.15	m
Stack length	.6	.115	m
Air gap	3	5	mm
Weight of active iron	7198	3303	kg
Copper weight	1902	1540	kg
Efficiency	.89	.85	
Power factor	.46	.34	
Rated slip	-.05	-.045	
Maximal torque	1.7	1.3	pu

Contrary to synchronous generators, induction generators may not be built with fractional slot windings if the slot number per pole and phase is lower than two. The reason is that the air gap leakage in this case will be unacceptably high for induction generators.

An induction generator for 4 MW and 25 rpm will thus have a very high leakage reactance and consequently, a small short circuit current. Because of the large air gap the magnetizing current will be extremly high. The maximal torque and the maximal output for such a generator will ,therefore, be very low if a reasonable amount of active material is used. It seems that an induction generator of this size cannot be built within acceptable economical limits.

COMPARISON TO STANDARD GENERATORS EQUIPPED WITH GEAR BOXES.

In order to get a rough comparison of weight and cost to standard generators equipped with gear boxes, some basic data were obtained from manufacturers of generators and gear boxes. The generators are standard synchronous and induction generators with two pole pairs (synchronous speed at 1500 rpm with 50 Hz). The weights given are the total weight of the machine, which of course is more than the calculated weight of active material of the low speed generators.

The weight and cost of the gear boxes are estimated values from a fabricated wind energy converter gear box. The cost and the weights were scaled in relation to the rated torque (the same number of stages in the gear boxes assumed). The gear boxes have a overload capability of two times the rated torque. The cost of the gearless low speed generators are estimated with the price of 100 Skr/kg active material. The cost of the frequency convertor is not included. All prices are given in Swedish currency (1 US $ = 6.95 Skr in October 1986).

standard

synchronous	206	1 700	4 200	kVA
50 Hz	91.0	95.4	95.5	% (efficiency)
	651	4 000	8 600	kg
	35	300	625	10^3 Skr
induction	200	1 500	4 000	kVA
50 Hz	880	4 600	9 200	kg
	110	300	675	10^3 Skr
gear box	314	4 410	18 800	kg
	70	991	4 237	10^3 Skr

low speed

synchronous	70	100	100	Hz
	85.9	91.0	91.3	% (efficiency)
	1 127	5 937	16 421	kg
	113	594	1 642	10^3 Skr
induction	100	100		Hz
	86	85		% (efficiency)
	1 700	4 800		kg
	170	480		10^3 Skr

The comparison shows that gearless synchronous generators could be a competitive alternative for larger wind energy converters. The additional cost of the frequency convertor needed and the inactive material increases however the cost of the low speed generators given above.

CONCLUSIONS

In this paper the outline of a design of high frequency low speed gearless wind turbine generators is presented. By increasing the generator frequency with frequency convertors, the active material of the generator can be reduced which reduces the weight and cost of the generator.

Two different types of generators were investigated; synchronous and induction genertors. The results indicate that the necessary large air gaps of these machines give a low power factor for the induction generators, which will influence the design of the frequency convertor. With synchronous generators the necessary extra air gap mmf can be produced with the field windings at large air gaps.

A cost and weight comparison with standard synchronous generators equipped with gear boxes is also made. The comparison indicates at this stage that the high frequency low speed synchronous generators could be a competitive alternative for larger wind energy converters.

REFERENCES

[1] "Wind energy converter with low speed generator" (in Swedish)
I. Nygren, S. Grop, S. Petterson
National Energy Administration, Sweden, NE 5061 541, 1981

[2] "Gearless Drive for an Ore Grinding Mill"
L. Slatinka
Brown Boveri Review, 4-86

[3] "Design of electrical machines" (in Swedish)
S. Lagerkvist
CTH, Göteborg, 1963

[4] "Die elektrischen Maschinen"
M. Liwschitz
Teubner, 1934

APPENDIX I

The air gap power in a generator is created by cooperation of a flux density wave and a current density wave. The expressions for these waves may be written in the following form:

$$B(x) = B \cos(px) \qquad (A1)$$

$$A(x) = \sqrt{2}\, A \cos(px + \phi) \qquad (A2)$$

p is the number of pole pairs, B is the peak value of the air gap flux density and A is the rms value of the linear current density. ϕ is the displacement angle between the waves. The force acting on an element of the stator perifery with the length L and the width dx is:

$$dF = B(x)\; A(x)\; L\, dx \qquad (A3)$$

Inserting the expressions (A1) and (A2) in (A3) and integrating the expression over the perifery one gets the perifery force:

$$F = \frac{\pi}{\sqrt{2}} B\; A\; L\; D_\delta \cos\phi \qquad (A4)$$

and the air gap power:

$$P_\delta = F\, v = \frac{\pi^2}{\sqrt{2}\, 60} B\; A\; D_\delta\, L\, n \cos\phi \qquad (A5)$$

MECHANICAL AND PUMPING OPERATIONS

NEW DEVELOPMENTS IN CANADA IN WIND POWERED WATER PUMPING

Jason Edworthy
Nor'wester Energy Systems Ltd.
Calgary

In the past five years the topic of remote water pumping has become an important one in western Canada, due to severe and continuing drought conditions, which were only slightly mollified in 1986. It was farsighted and timely that the Lethbridge Wind Turbine Test Facility, intended primarily for alternate energy water pump testing, was set into operation during this period.

In Canada, and many parts of the world, the old "American" water pumper is what we typically think of for water pumping. But now, Canadians, and others, are developing remarkable and innovative new technologies.

The Lethbridge Test Site, as discussed more in another paper at this conference, is intended to demostrate a variety of machines in a similar configuration typical of prairie use. The site is well instrumented with anemometers, computer data acquisition systems, and other equipment. A number of pad sites are available, and through the years of operation they have been nearly 100% occupied. The site is very typical of the praires, and farm use, with good flat exposure and nearby treed wind breaks.

Initially, water pumping equipment seen and tested at this site and at other Canadian locations were not manufactured in Canada, or they were essentially quite old designs with little or no recent modifications. Some quite innovative foreign manufactured systems were brought in and tested. Just about one year ago, a report about the first several years of testing was released.

The report contains a number of graphs and tables indicating flow in different wind speeds for the different machines. One graph which was not available was Figure 1, which indicates all the initially tested units, at 6 m lift, presented on the same scale. From this, it can be seen that two units produced far more that the general group: the Wind Baron and the Graham. They were large area of capture machines, with correspondingly large pistons to pump water. Unfortunately there were problems. The Wind Baron kept losing the turbine head in high winds.

Figures 2 and 3 show the same data without the Wind Baron and the Graham, respectively. It is certainly no accident that I show this latter view, as Nor'wester's system, a low voltage DC wind electric one, worked very well.

I divide modern water pumping systems into two main types: mechanical and electrical (Figure 4). I further them into in-situ and "removed" systems.

The standard system is shown in Figure 5: a high torque mechanical turbine head driving a vertical pumping shaft, with a piston down a well. There are many versions of this, with interesting improvements to blades, transmissions, pistons, and other components. Good examples of these type of systems include the Deltx Windpump, the Chinook from Calgary and Dr. Kentfields new low cost design, described elsewhere at this conference.

Another mechanical type is the air lift (Figure 6), of which the Bowjon, and some of Buck Massey's Maverick units are good examples.

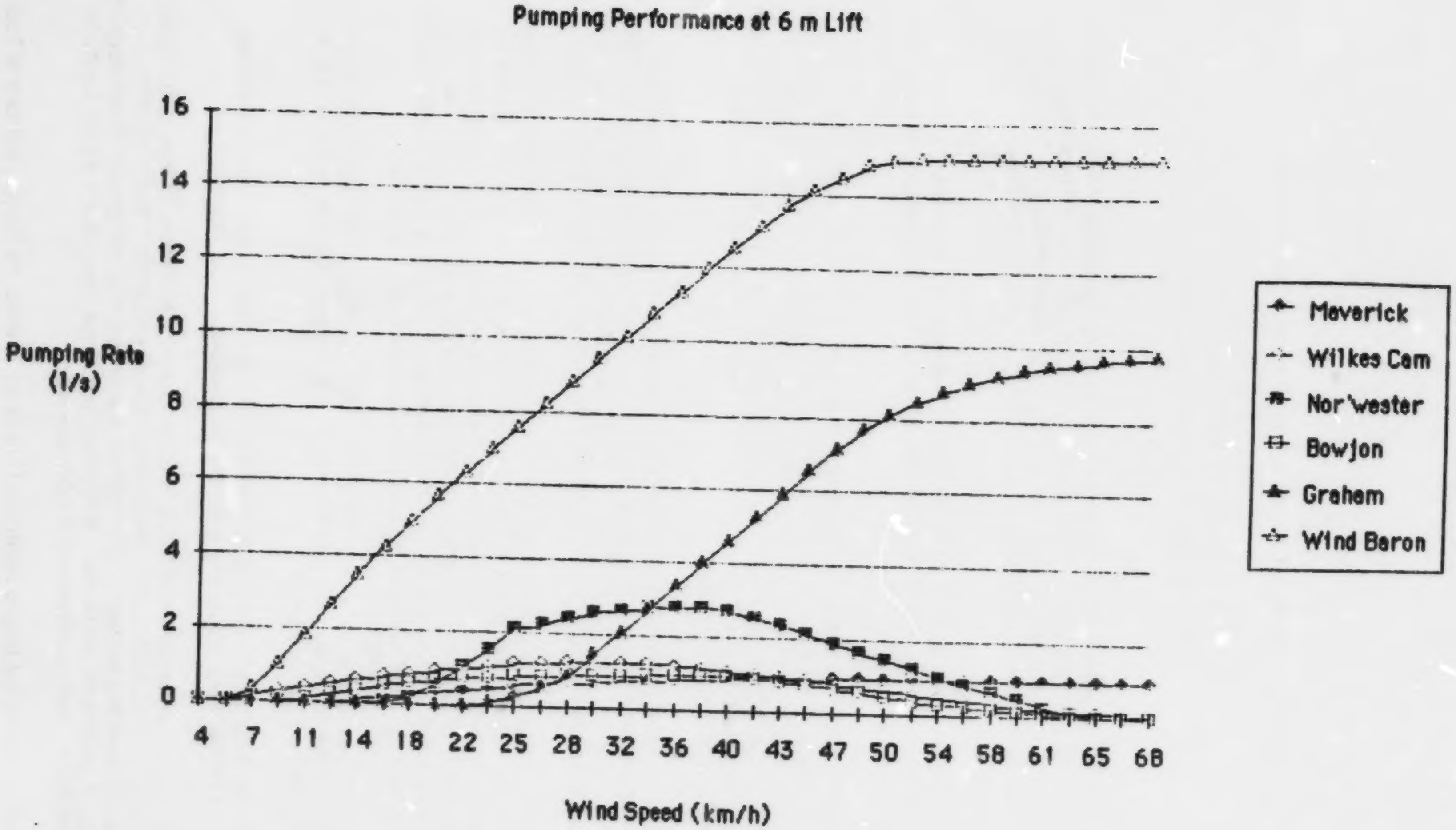


FIGURE 1

Nor'wester Energy Systems Limited 1986

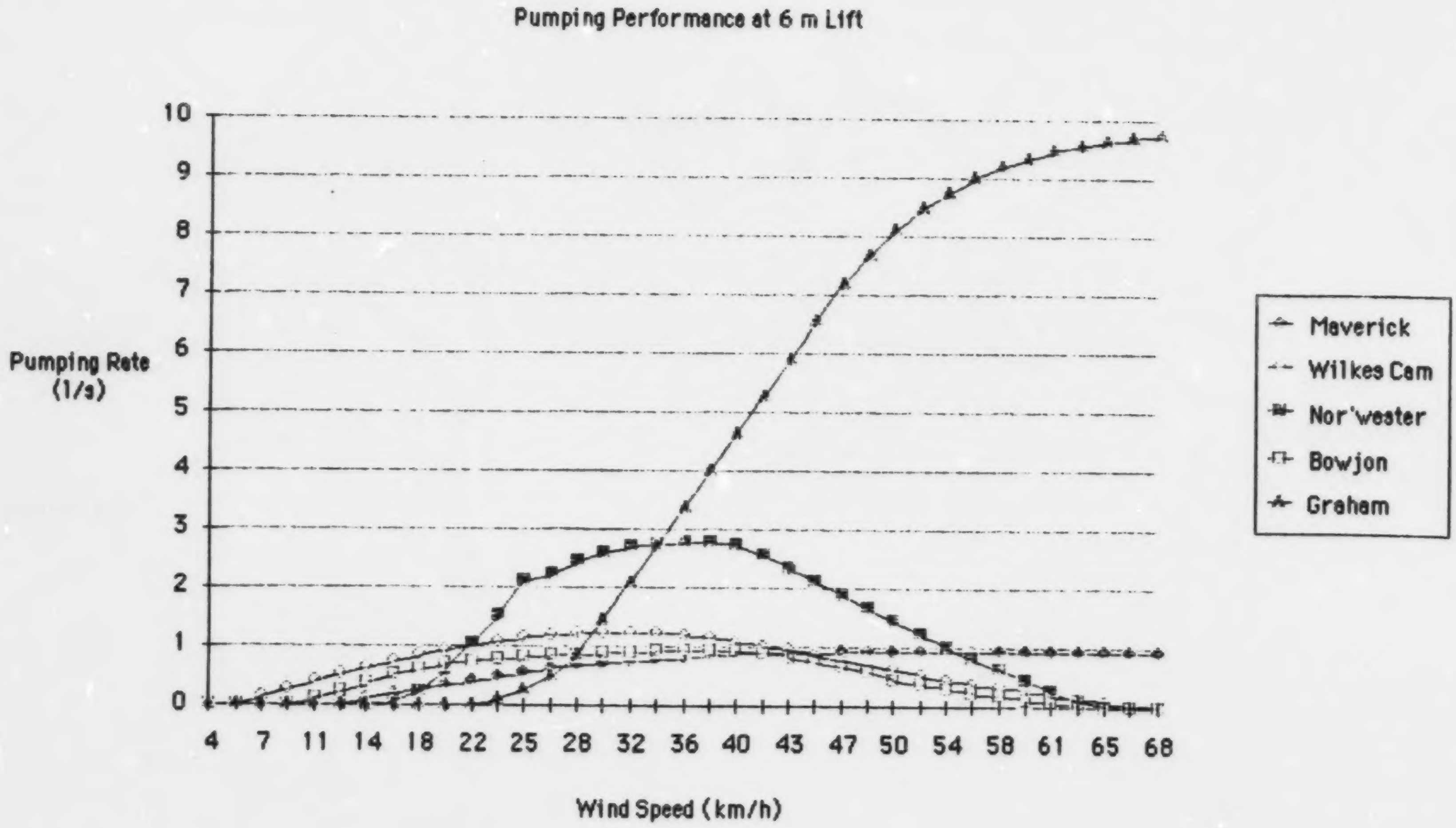


FIGURE 2

Nor'wester Energy Systems Limited 1986

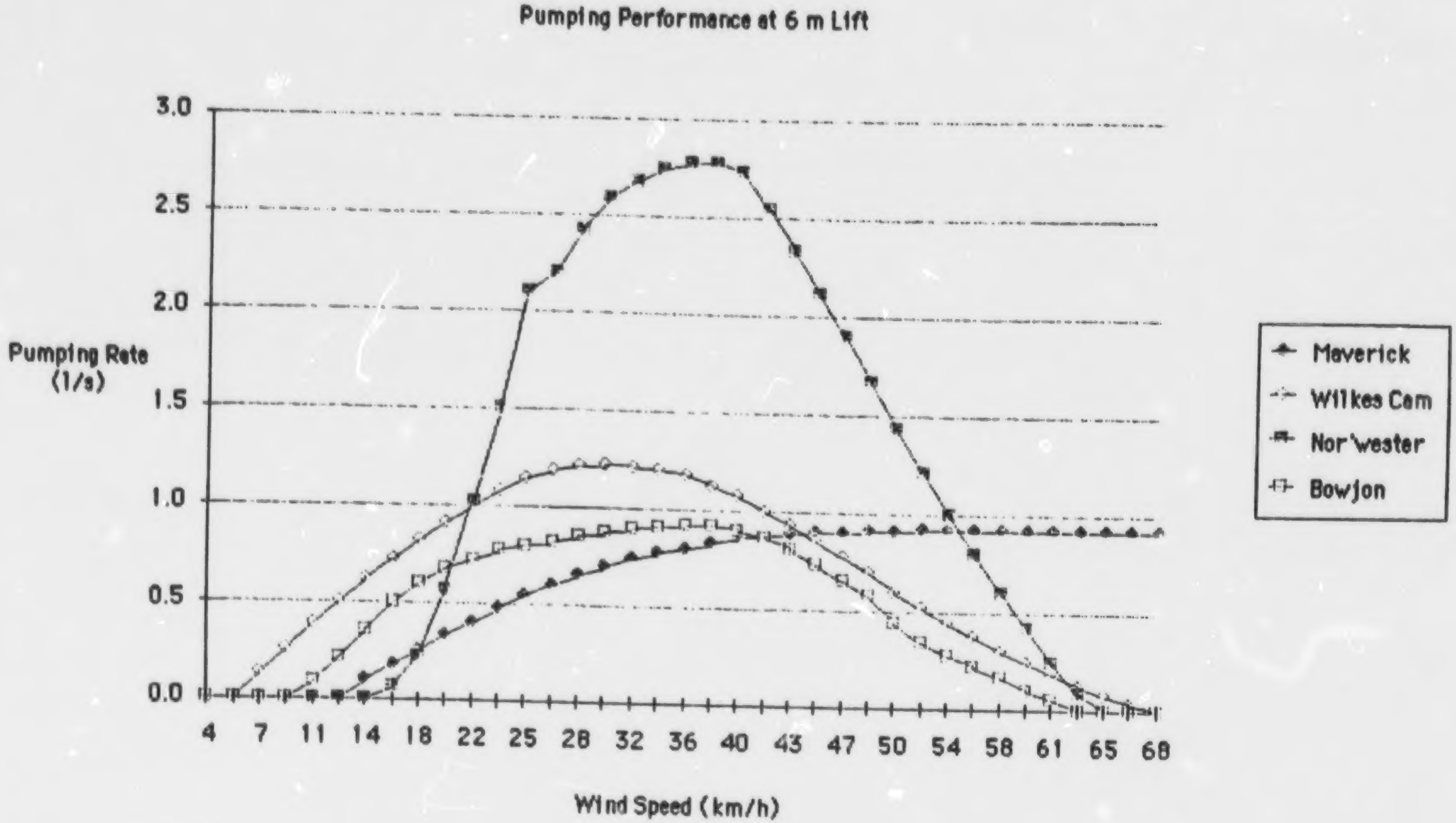


FIGURE 3

Nor'wester Energy Systems Limited 1986

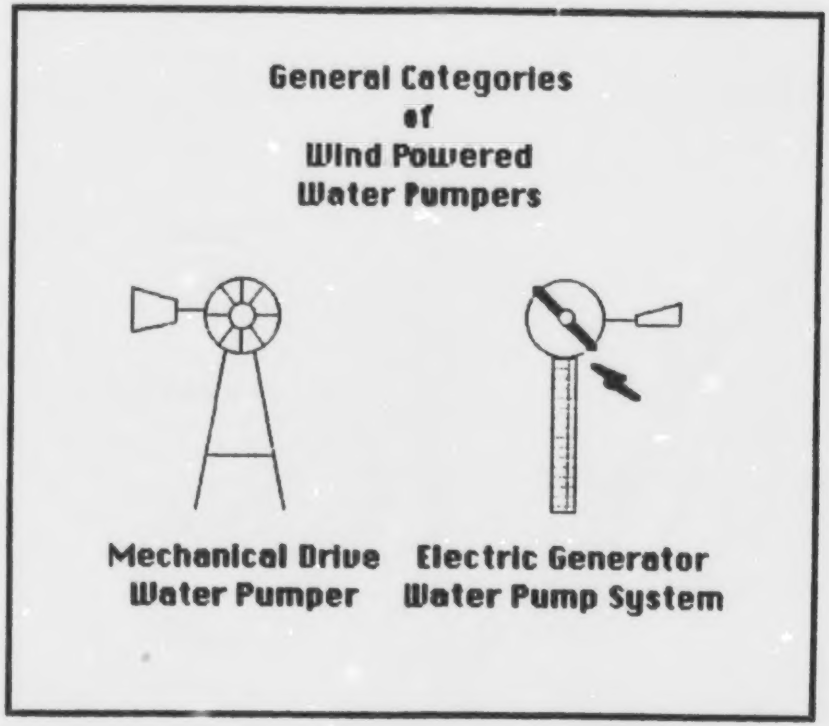

General Categories
of
Wind Powered
Water Pumpers
Mechanical Drive
Water Pumper
Electric Generator
Water Pump System

FIGURE 4

Mechanical Piston Pump System

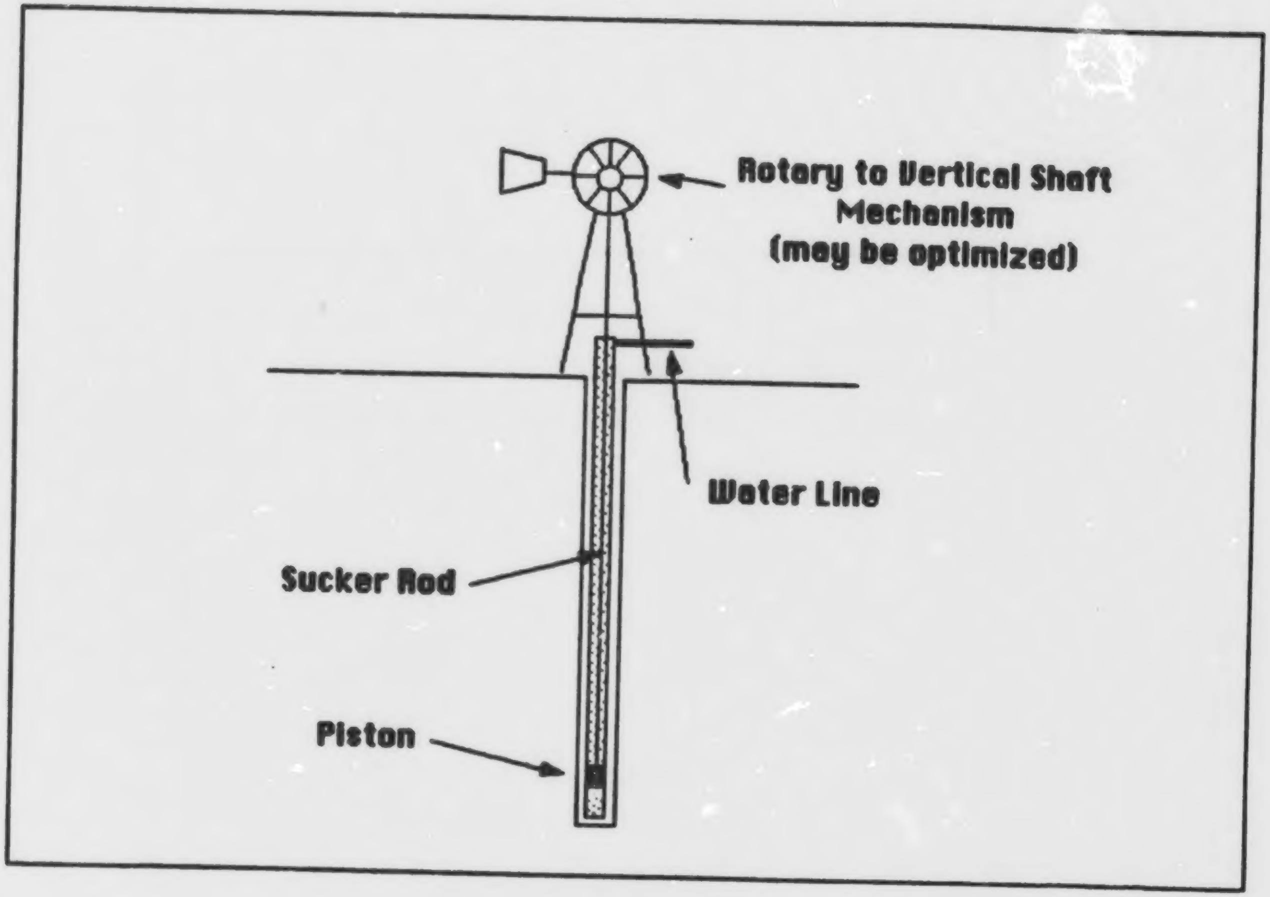

Rotary to Vertical Shaft Mechanism (may be optimized)
Water Line
Sucker Rod
Piston

FIGURE 5

Mechanical Air-Lift Pump System

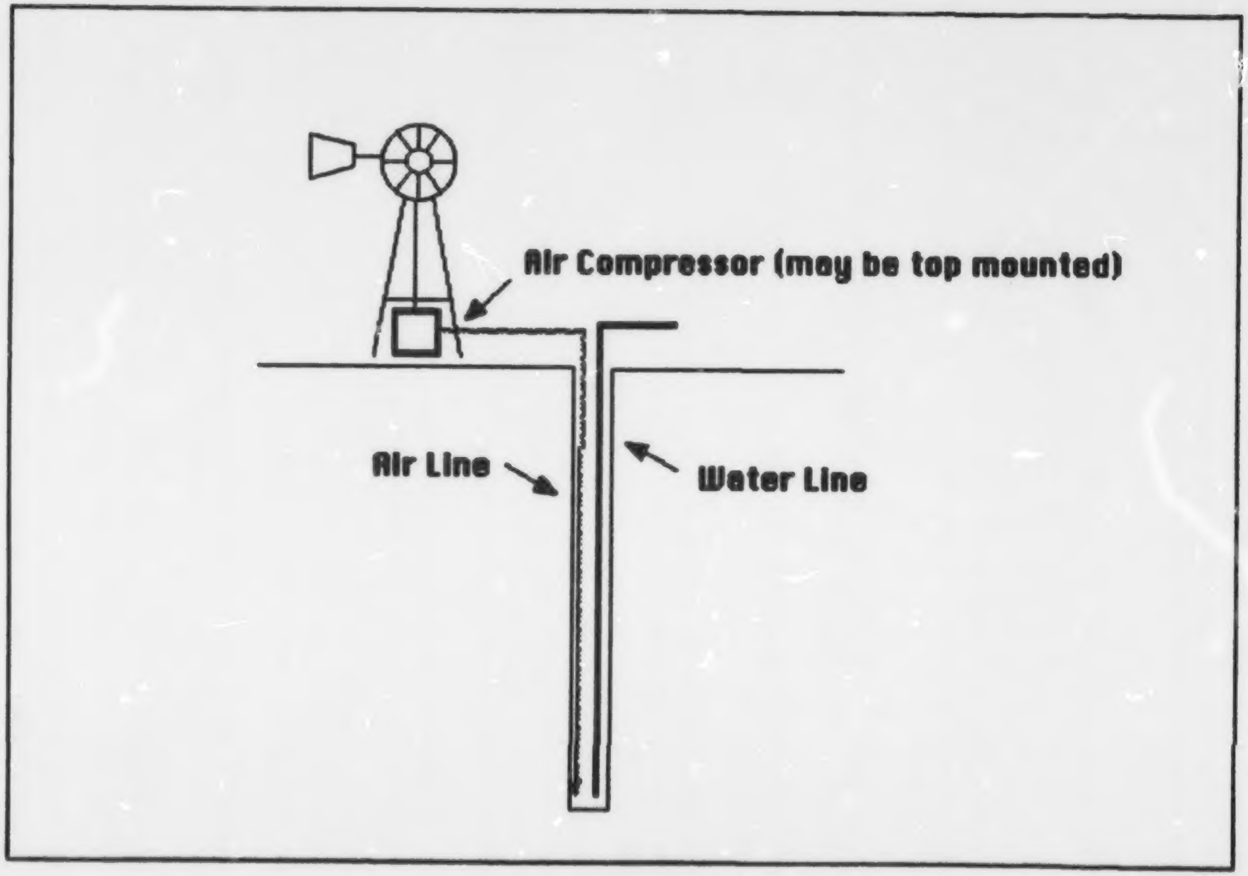

Air Compressor (may be top mounted)
Air Line
Water Line

FIGURE 6

Nor'wester Energy Systems Limited 1986

An extremely old, perhaps ancient type, newly renovated in Alberta, is Buck Massey's mechanical drive helical pump (Figure 7). This innovative design uses a simple variable pitch rotor in a downwind design, free base located yaw, and mechanical drive rotary cable to transfer energy.

Some designs are mechanical systems which may be "removed". This refers to the capability to site the turbine away from the well, an obvious benefit in the prairies where water is often deep in coulees and gullies - not on windy hilltops. Some of the drawings shown are taken, with changes, from work by Peter Fraenkel of the UK, shown recently in an article by Mark Newham in the June issue of Windpower Monthly (Denmark). In this case, a pneumatic system, like a standard air compressor, drives a pneumatic pump (Figure 8). This type of system could also drive an air lift unit.

Similarly, Figure 9 shows a hydraulic system drive. Buck Massey has used hydraulic systems in some versions of his Maverick units.

Also considered, and in some places developed, is a mechanical shaft system, with modern flexible couplings (Figure 10).

A system which uses cables, or linkages, to transfer energy to the pumpsite is shown in Figure 11. This is not so unusual, as Dr. Kentfield and Deltx have proposed a similar system, with good capabilities to 1000 ft.

The Fraenkel study, which considered various options under 1 kW and to 400 m, indicated that systems using low pressure pneumatic transmissions, ie. with air, produce the best water delivery for the lowest cost. This option is one of the few not yet used by Canadians, and I am sure that it will soon be incorporated into Canadian research.

In electrical systems, I define the most basic one as a DC turbine, wired to a DC motor, driving a pump (Figure 12). This was the basis of Nor'wester's first unit, the WPS-I. In fact, the turbine may be AC, with rectification at the turbine or prior to the motor. This system is limited in distance due to high DC line loses and high cut in wind speed. There are also problems with varying speeds with many types of pumps, causing low efficiencies. Our WPS-I used a 30 year old re-manufactured Wincharger, and worked well.

Another method, not yet used in Canada that I am aware of, is the use of a 3 phase AC turbine to drive a similar motor, driving a pump (Figure 13). This is attractive for large pumping loads, with good startup capabilities and low maintenance, high efficiency motors. Whirlwind has long promoted this method, as have Bergey Windpower more recently. There remain problems with high cut-in speeds, and variable speed driving of pump impellers.

The most sophisticated design (Figure 14) using an electric turbine solves most of these problems, but costs are higher. This system uses battery storage of either DC or rectified AC energy, inverted to provide utility grade AC power, at for example 120 VAC, 60 Hz, 1 phase. AC transmission is less expensive than DC, and off the shelf pumps may be used, whether centrifugal, jet-type or submersible.

This system provides "removed" capability, gets around problems of high cut-in speed with battery storage, and uses the pump efficiently by driving it at a constant speed.

This concept is not new (eg North Wind has put similar packages together) but the Canadian application of it, sized and designed for our use, is.

Mechanical Rotary Pump System

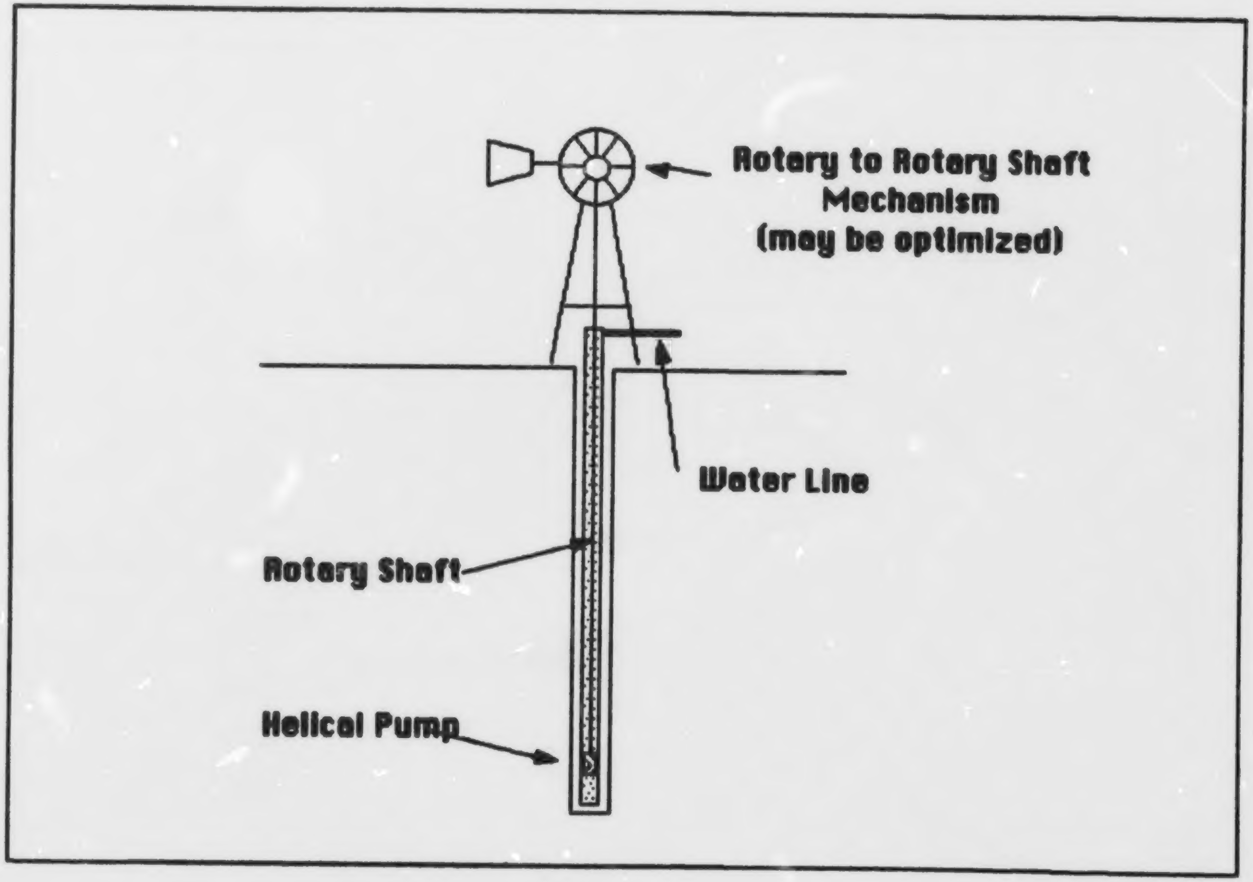

Rotary to Rotary Shaft
Mechanism
(may be optimized)
Water Line
Rotary Shaft
Helical Pump

FIGURE 7

Mechanical Pneumatic Pump System

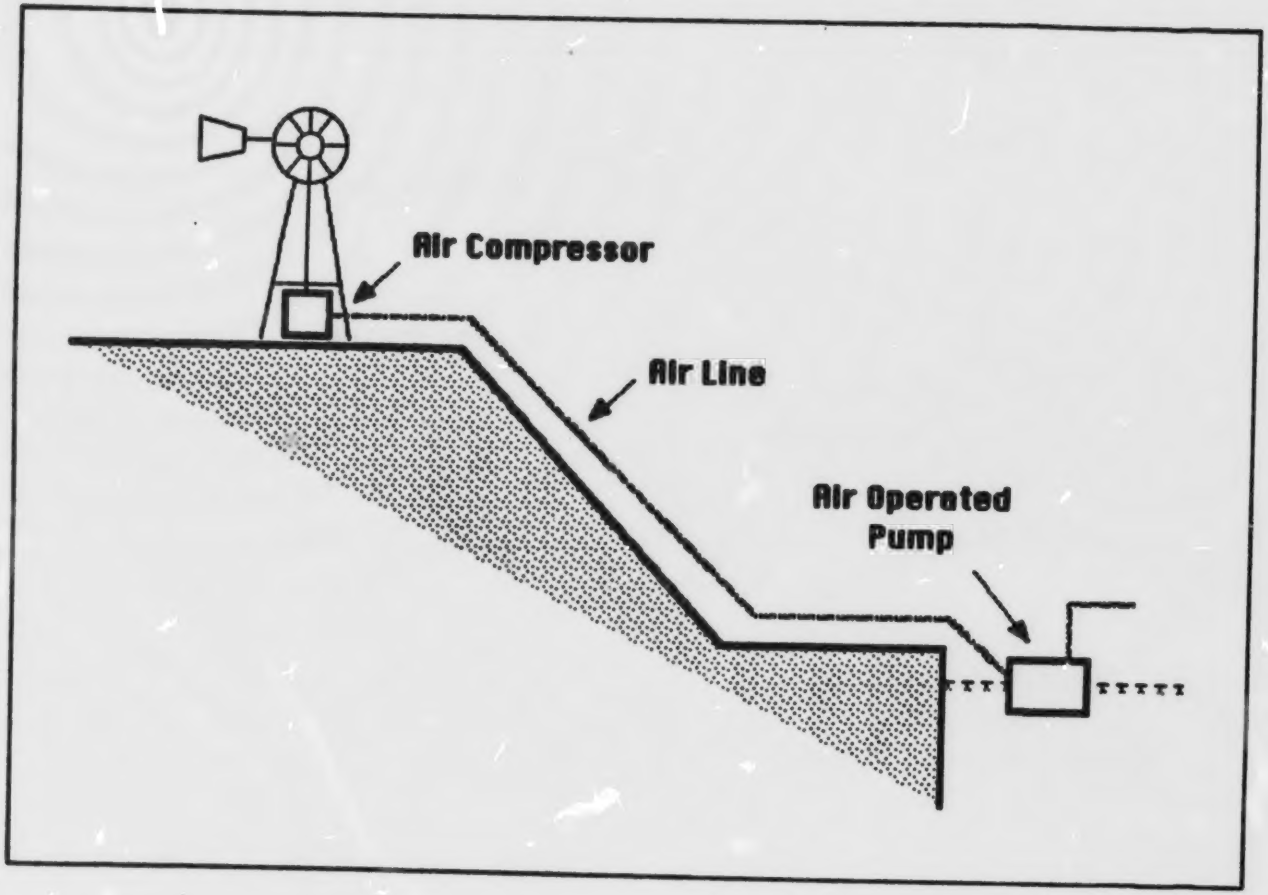

Air Compressor
Air Line
Air Operated Pump

FIGURE 8

Nor'wester Energy Systems Limited 1986

Mechanical Hydraulic Pump System

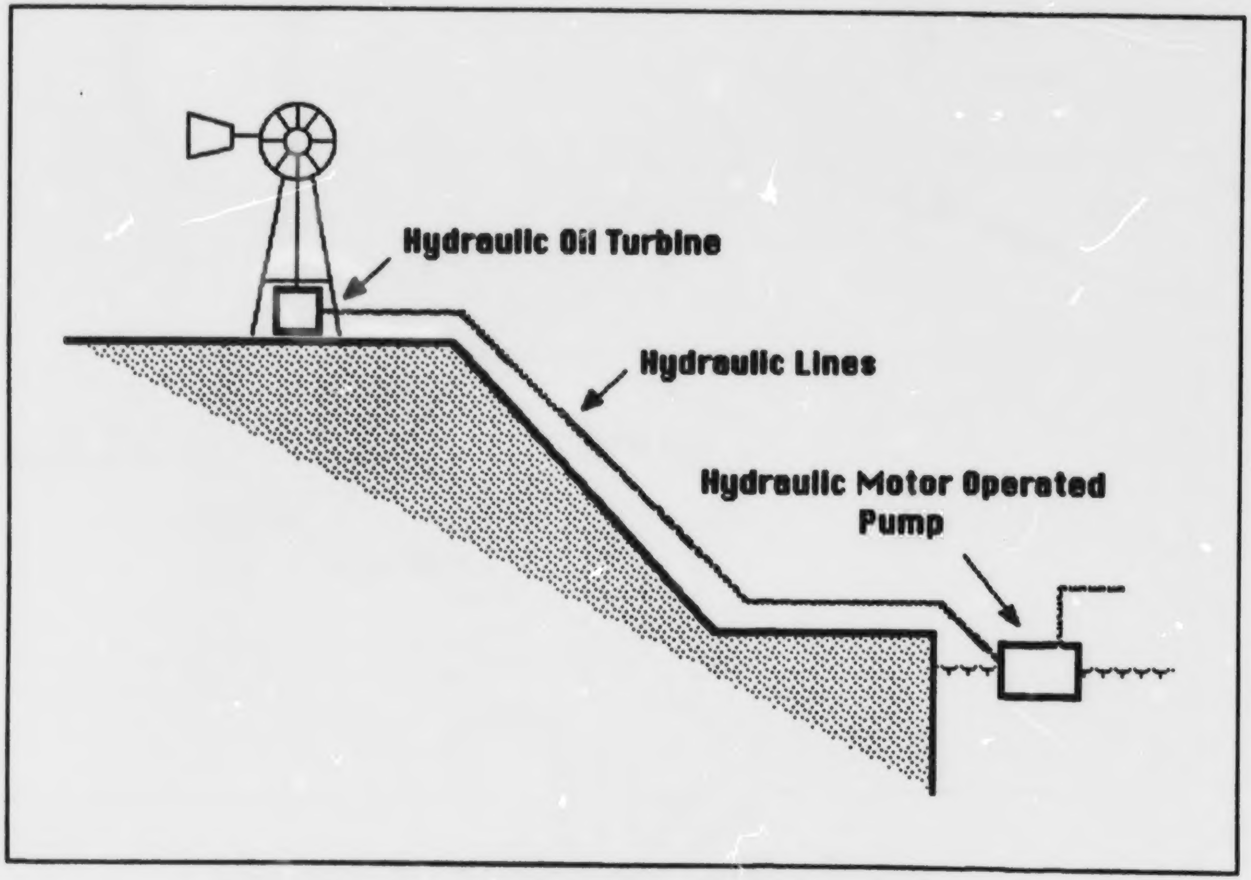

Hydraulic Oil Turbine
Hydraulic Lines
Hydraulic Motor Operated Pump

FIGURE 9

Nor'wester Energy Systems Limited 1986

Mechanical Rotary Shaft Pump System

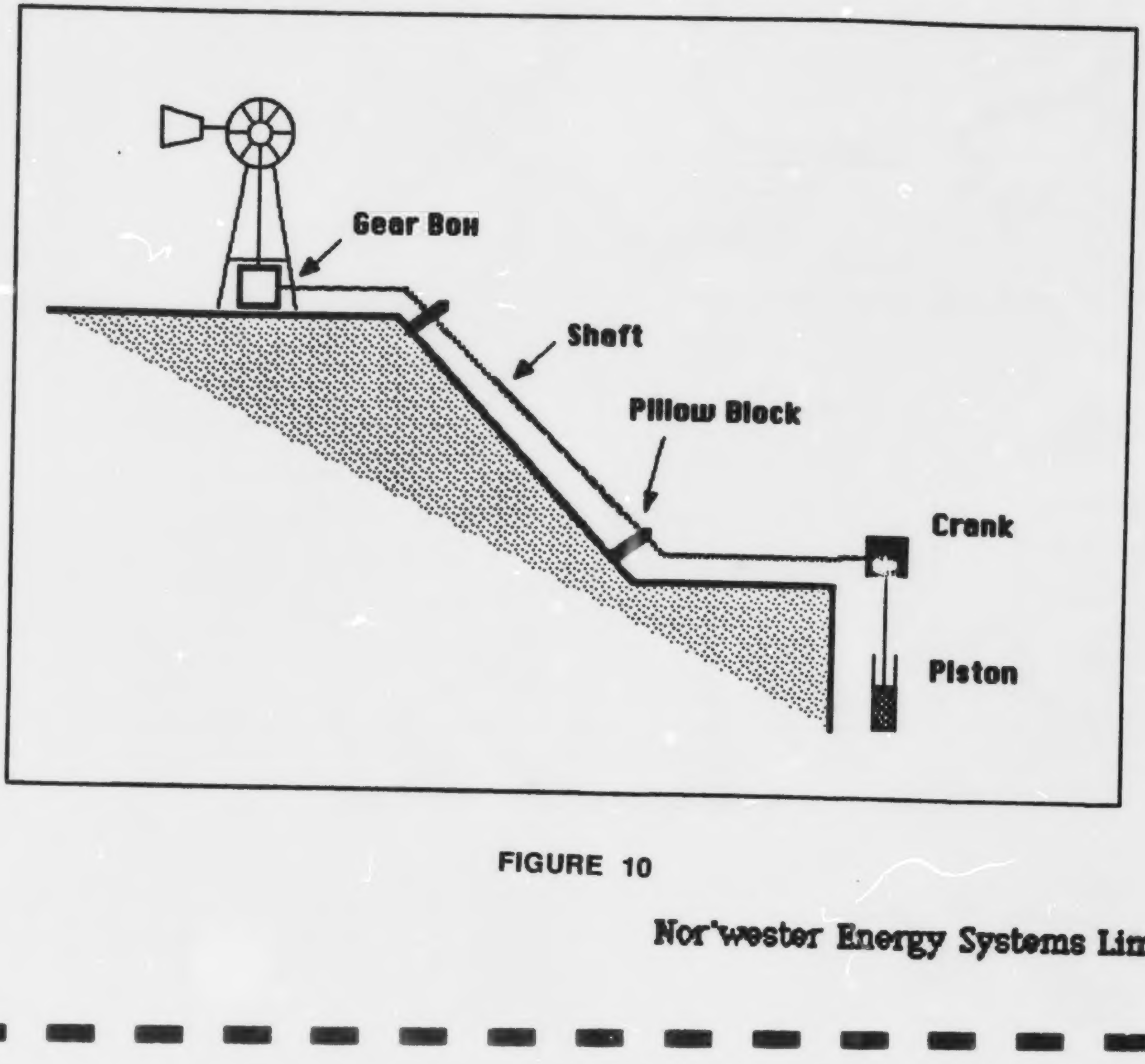

Gear Box
Shaft
Pillow Block
Crank
Piston

FIGURE 10

Nor'wester Energy Systems Limited 1986

Mechanical Transmission Pump System

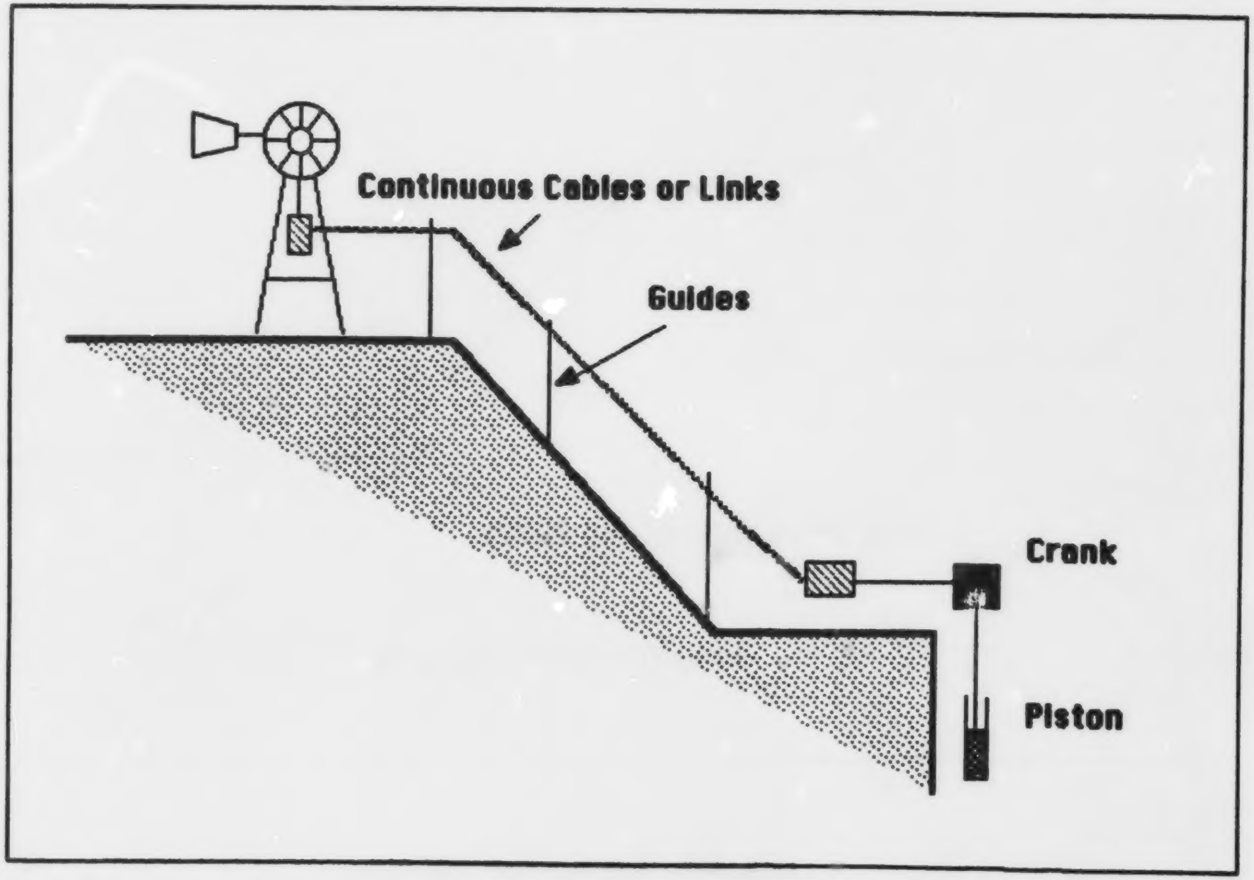

Continuous Cables or Links
Guides
Crank
Piston

FIGURE 11

Nor'wester Energy Systems Limited 1986

Electric DC Pump System

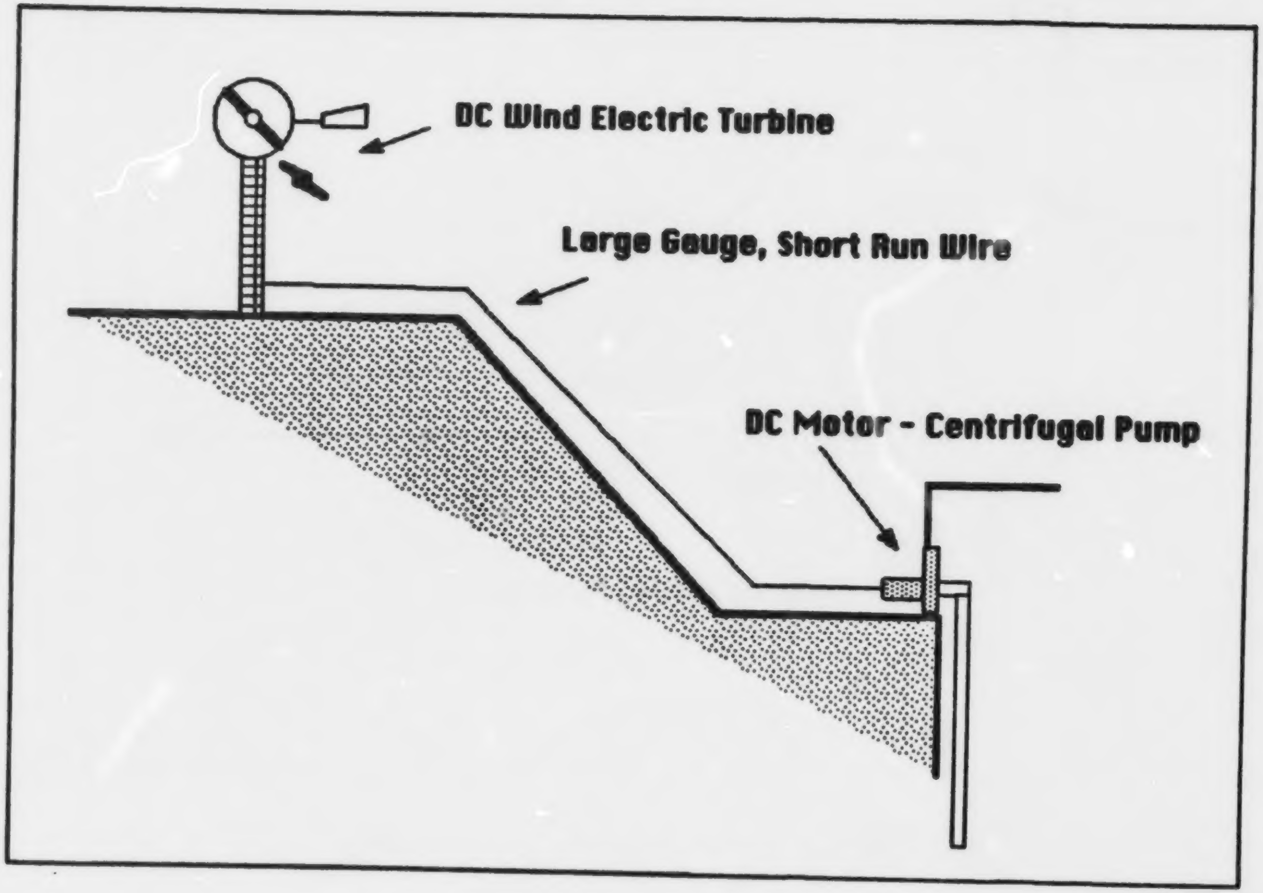

DC Wind Electric Turbine
Large Gauge, Short Run Wire
DC Motor - Centrifugal Pump

FIGURE 12

Electric AC Pump System

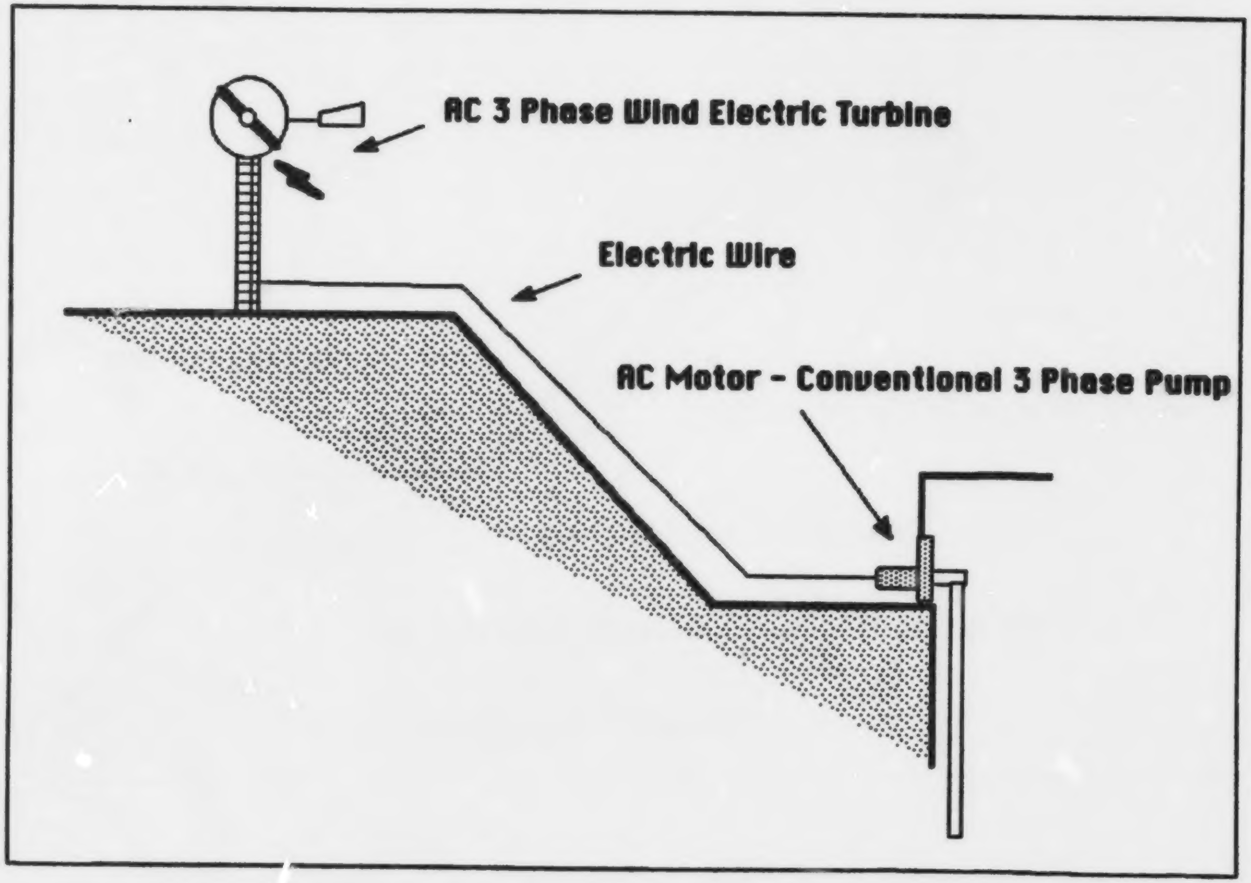

AC 3 Phase Wind Electric Turbine
Electric Wire
AC Motor - Conventional 3 Phase Pump

FIGURE 13

Nor'wester Energy Systems Limited 1986

Electric DC Storage - AC Pump System

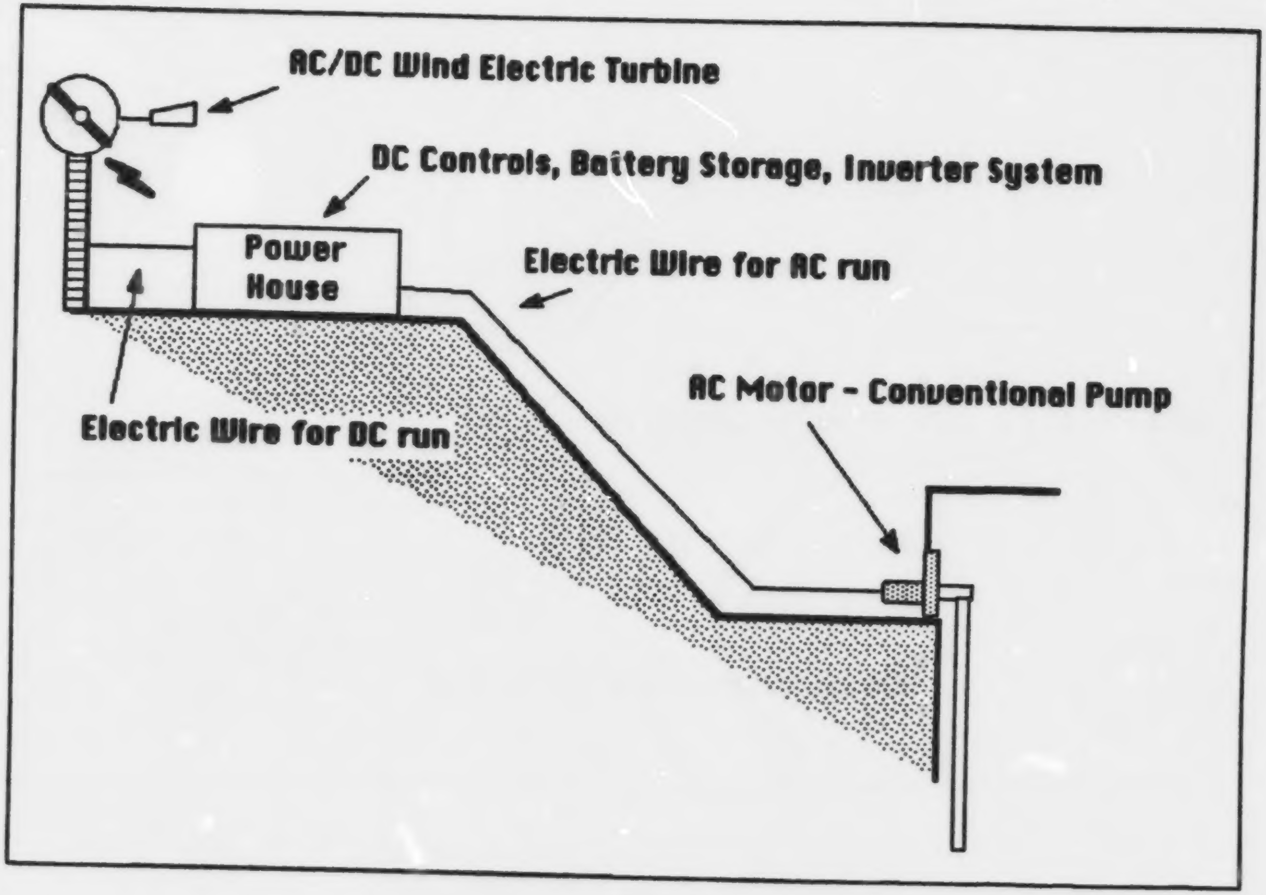

AC/DC Wind Electric Turbine
DC Controls, Battery Storage, Inverter System
Power House
Electric Wire for AC run
AC Motor - Conventional Pump
Electric Wire for DC run

FIGURE 14

Nor'wester Energy Systems Limited 1986

Nor'wester's design is called the MAESTRO. It has recently been installed at Lethbridge, and only manual data are available to date. We use a modern rugged low maintenance turbine, in this case a Bergey 1000 watt unit. It is installed on a tilt tower of our own design and manufacture, raised with a winch system. This provides easy access for inspection and maintenance. The PowerHouse contains controls, batteries, inverter and at this site a 1/2 hp Monarch pump. This system also provides additional 120 VAC outlets for the use of tools at the site - very handy for farmers and ranchers, and potentially useful for 3rd world applications.

Initial measurements at the site with a 6 m lift indicate constant flows of 45 gpm or about 3.5 litres/sec (Figure 15). Of course, with battery storage, so long as sufficient wind is present to maintain charge, the system will pump at full capacity even with no wind, or while the tower is tilted down for inspection. Figure 16 compares the MAESTRO to findings shown earlier for small flow water pumpers initially tested at the site.

The Lethbridge test site has certainly assisted the creativity and development of water pumping technology in Canada, particularly in Alberta. Domestic sales, from site visits and demonstration days, are beginning to take off. Foreign sales have not yet occured to any great extent, but the interest is high. We have received enquiries from the Arab states, Africa, Caribean, India and the USA. In particular, all these systems hold promise for 3rd world applications, especially Buck Massey's and John Kentfields's inexpensive, effective systems. We at Nor'wester hope that the double provision of water, and electricity, will gain us a market niche there, too.

Canadian development in this technology has not concentrated in one particular area, nor with any one group. It has been primarily spawned by small companies or individuals, conducting their own R & D in-house, and occasionally by a university researcher. Few firms have made the efforts to acquire specific outside funding from government or investors; instead they have preferred to work on their own. This should bode well for the industry, as it will continue to develop with a capability to respond to real markets, and an ability to withstand the "variable breezes" of other, outside funding sources.

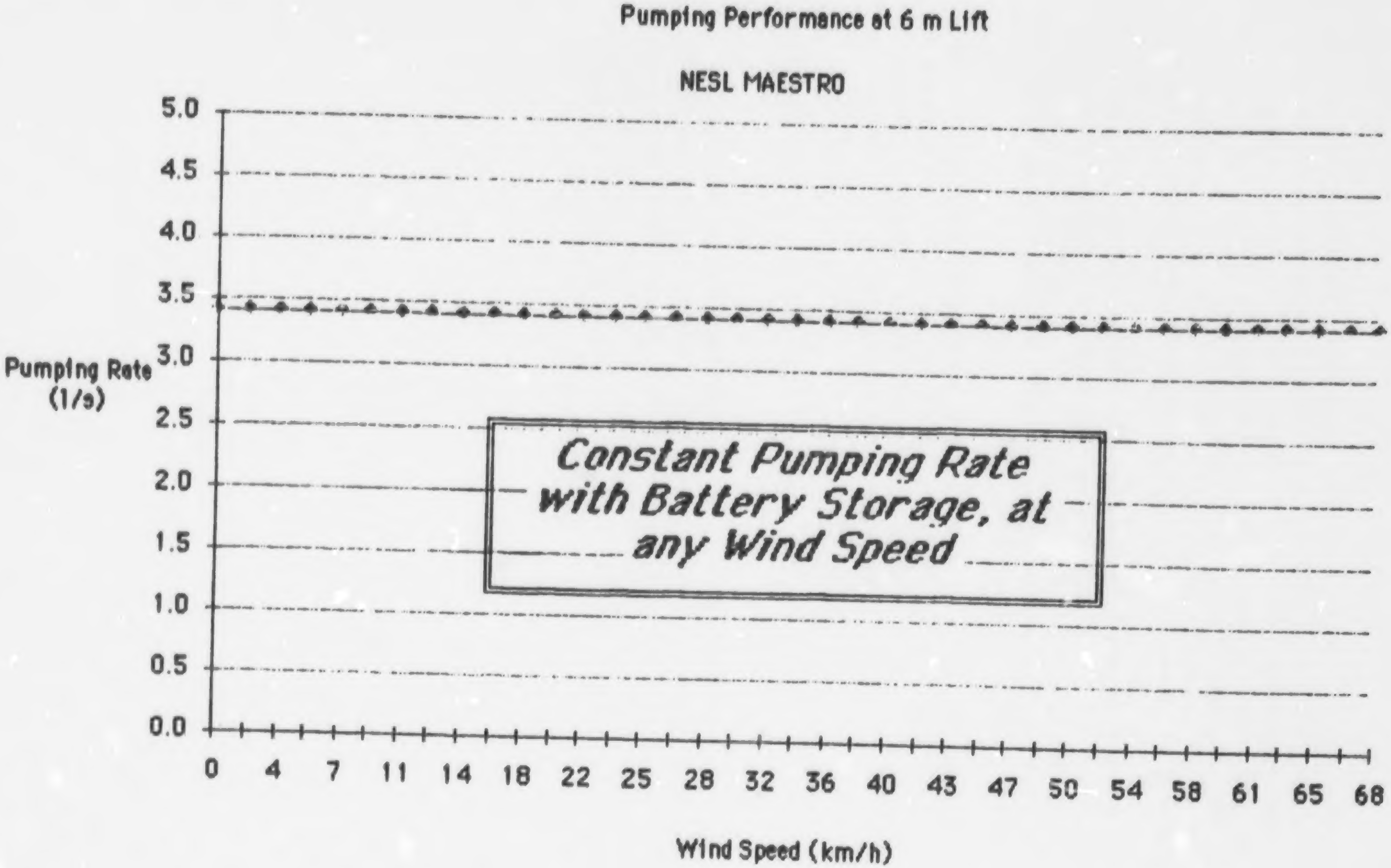


FIGURE 15

Nor'wester Energy Systems Limited 1986

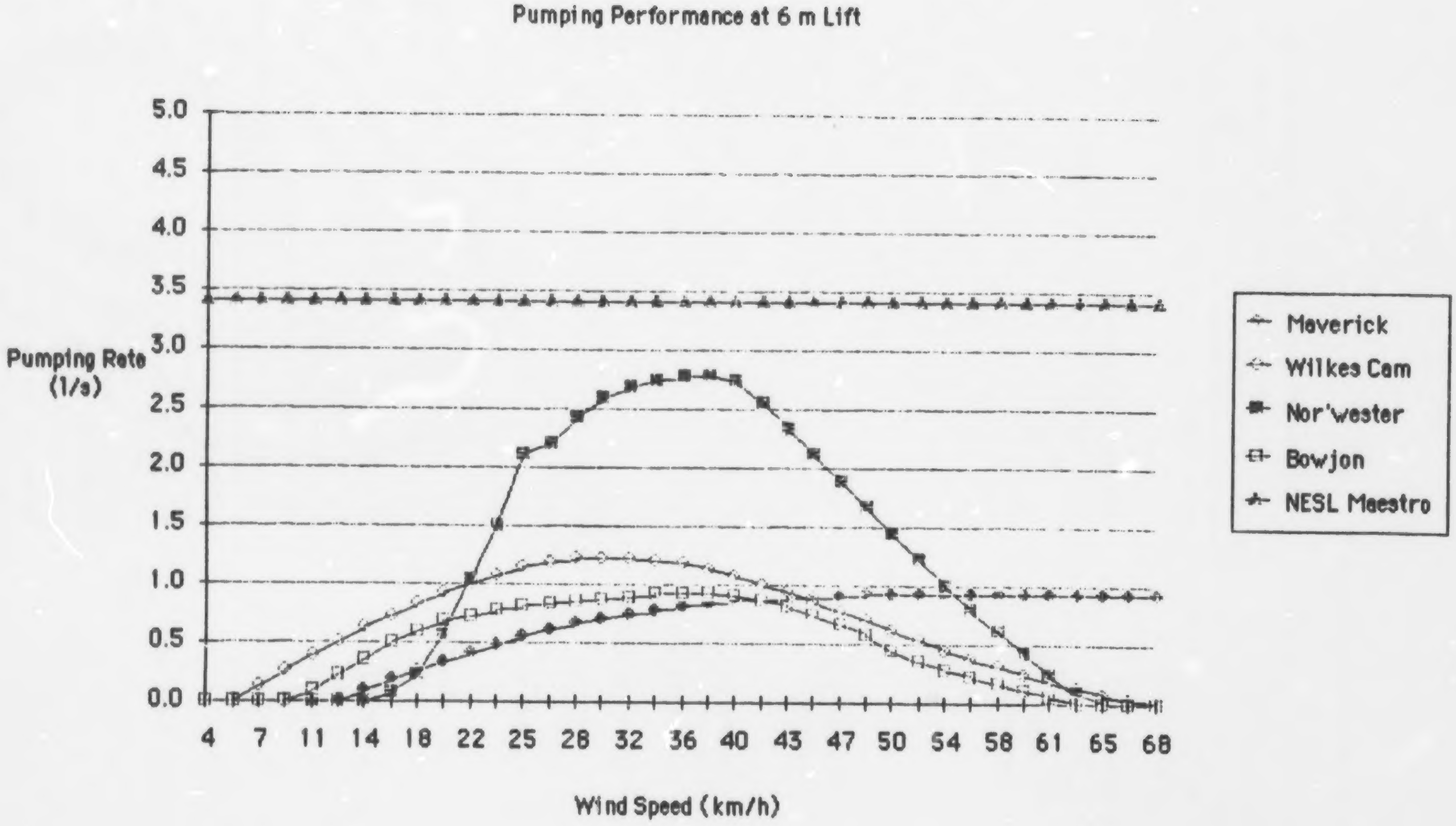


FIGURE 16

Nor'wester Energy Systems Limited 1986

Slides List for Jason Edworthy, CanWEA '86, Quebec City

The presentation is set up to coincide 60 slides with the talk. Each slide change is indicated by a high pitched "beep". The beep comes from a small toy which also buzzes on occasion, so you may also hear that!! At the start and on one of two slides, there are "registration points" where you can check that the slide and talk correspond. Most will be obvious, especially if you have run through the show once. This would be a very good idea if there is time, as it will then look more professional for all. My sincere thanks for the help in doing this!

Slide #	Photo Subject	Approximate Vocal Portion
1	Black	Front End Filler. Go past this to start show.
2	Company Title	At beep, go past.
3	Presented by Jason...	At beep, go past.
4	Jason in front of turbine	"Hi, I'm Jason Edworthy. Bonjour, je suis JE. I am very pleased to have this opportunity to present my paper to you, but I sincerely regret not being able to be here in person.
5	Nor'wester brochure	As you know, I own and operate NESL, an Alberta firm which manufactures and distributes wind, hydro and solar energy equipment. Some of our promotional material is available here.
6	Nor'wester Hat	This is the hat I wear doing this [REGISTRATION OF SLIDES]
7	Cowboy Hat	However, this is the hat most of you are used to seeing on me. Sometimes I get questions about my hat...well its easy to explain:
8	Jason riding horse	You see, my friend Buck here just expects me to wear it
9	Closer view of horse	and now its a real habit, however and whenever I travel.
10	Dutch Windmill & Canal	This presentation concerns the pumping of water by wind power.
11	Prairie scene, water pumper	In Canada, and many parts of the world, this is what we typically think of for water pumping. But now, Canadians, and others, are developing remarkable and innovative new technologies.
12	Map of Alberta	Much of this activity is occuring in Alberta, primarily focussing on an excellent facility in Lethbridge (indicate where that is)
13	Lethbridge Test Site	The test site, as discussed more in antoher paper this sessio, is intended to demostrate a variety of machines in a similar configuration typical of prairie use.
14	Anemometer Tower	[REGISTRATION OF SLIDES] The site is well instrumented with anemometers, computer DA systems, etc.
15	View of test site	A number of pad sites are available, and through the years of operation they have been 100% occupied.
16	View of site (puddle)	The site is very typical of the praires, and farm use, with good flat exposure and nearby treed wind breaks.
17	Report	Just about one year ago, a report about the first several years of testing was released.
18	Graph (2 high lines)	The report contains a number of graphs and tables indicating flow in different wind speeds for the different machines. One graph which was not available was this one, which indicates all the initially tested units, at 6 m lift, presented on the same scale. From this, you can see that two units produced far more that the general group: Wind Baron and the Graham. They were large area of capture machines, with correspondingly large pistons to pump water. Very

		impressive to watch. Unfortunately there were problems. The Wind Baron kept losing the turbine head in high winds.
19	Graph (1 high line)	This is the graph rescaled without the Wind Baron. The Graham unit, now highest, was a large Savonius rotor with very good torque characteristics. Good enough to twist the entire top of the tower severely.
20	Graph-scaled to ~3l/s	This is the graph rescaled to show only the smaller output, successful units. It is certainly no accident that I show this view, as Nor'wester's system, a low voltage DC wind electric one, worked very well.
21	White/green Wincharger	Here are some views of the originally tested units. This is Nor'wester's re-manufactured 1200 watt Wincharger, which was hooked up, without storage, to a centrigual pump driven by a 0-60 VDC continous duty motor. The main criticism of this system was its high start up windspeed, compared to the other units.
22	Silver Wind Baron	This is the Wind Baron, 21 ft across. As I said, it kept losing its head.
23	Bowjon missing rotor	This is an unflattering view of a Bowjon, which I regret. I has no rotor in this photo, but that is not the usual case. This is an airlift system.
24	Distant shot of Wilkes Cam	This is a Wilkes Can unit, which like the Wind Baron is an optimized mechanical piston system.
25	Diagram of Mech - Elect Sys	I divide modern water pumping systems into two main types: mechanical and electrical. I further them into in-situ and "removed" systems.
26	Diag of std mech pumper	The standard system is this. A high torque mechanical turbine head driving a vertical pumping shaft, with a piston down a well. There are many versions of this, with interesting improvements to blades, transmissions, pistons, etc.
27	Chinook pumper	This large diameter unit just went into the Site, and is quite conventional. It has good furling characteristics and derives considerable energy from the large rotor.
28	Deltx (City in bkgd)	This is the famous Deltx windpumper, researched and designed by my friend and colleague Dr. John Kentfield.
29	Small Deltx at site	A scaled down version is at the Lethbridge site, but unfortunately it was not operational this season.
30	Distant shot of Kentfield Unit	As Dr. Kentfield is scheduled to tell you during this session, he continues his work at the University of Calgary with a new, low-technology wind pump system.
31	Diag of Air Lift type	Another mechanical type is the air lift, of which the Bowjon, and some of Buck Massey's Maverick units are good examples.
32	Diag of Helical pump	An extremely old (ancient) type, newly renovated in Alberta, is Buck Massey's mechanical drive helical pump.
33	Blue Massey unit	Buck Massey supplies a variety of pumps with his designs, and this ones uses the helical pump, which operates like an auger to raise water.
34	Blue Massey unit *2	A mechanical drive cable transfers energy from the rotor down to the base unit, which houses the pump.
35	Massey unit with person	This innovative design uses a simple rotor with variable pitch in a downwind configuration, yawing near the base.

36	Diag of Pneumatic remote Unit	Moving to mechanical systems which may be "removed". This refers to the capability to site the turbine away from the well, an obvious benefit in the prairies where water is often deep in coulees and gullies - not on windy hilltops. Some of these drwaings are taken, with changes, from work by Peter Fraenkel of the UK, shown recently in an article by Mrk Newham in the June issue of Windpower Monthly (Denmark). In this case, ap pneumatic system, like a standard air compressor, drives a pneumatic pump. This type of system could also drive an air lift unit.
37	Diag of Hydraulic remote Unit	Similarly, a hydraulic system drive. Buck Massey has used hydraulic systems in some versions of his Maverick units.
38	Diag of Mech Shaft System	Also considered, and in some places developed, a mechanical shaft system, with modern flexible couplings.
39	Diag of Mech Cable/Link System	A system which uses cables, or linkages, to transfer energy to the pumpsite. This is not so unusual, as Dr. Kentfield and Deltx have proposed a similar system, with good capabilities to 1000 ft. The Fraenkel study, which considered various options under 1 kW and to 400 m, indicated that systems using low pressure pneumatic transmissions, ie. with air, produce the best water delivery for the lowest cost. Although I do not agree with all his findings, this option is one of the few not yet used by Canadians, and I am sure that it will soon be incorporated into Canadian research.
40	Diag of DC Electric System	Moving from mechanical to electrical systems, I define the most basic ones a s DC turbine, wired to a DC motor, driving a pump. This was the basis of our first unit, the WPS-I. In fact, the turbine may be AC, with rectification at the turbine or prior to the motor. This system is limited in distance due to high DC line losses and high cut in wind speed. There are also problems with varying speeds with many types of pumps, causing low efficiencies.
41	Wincharger in shadow	Our WPS-I used a 30 year old re-manufactured Wincharger, and worked well.
42	Diag of AC 3 Phase System	Another method, not yet used in Canada that I am aware of, is the use of a 3 phase AC turbine to drive a similar motor, driving a pump. This is attractive for large pumping loads, with good startup capabilities and low maintenance, high efficiency motors.
43	Whirlwind unit on display	Whirlwind has long promoted this method, as have Bergey Windpower more recently.
44	Close view of Whirlwind	Whirlwind uses their robust SWEC systems for this type of application. There remain problems with high cut-in spee;ds, and variable speed driving of pump impellers.
45	Diag of AC Storage type System	The most sophisticated design using an electric turbine solves most of these problems, but costs more. This system used battery storage of either DC or rectified AC energy, inverted to provide utility grade AC power, at for example 120 VAC, 60 Hz, 1 phase. AC transmission is less expensive than DC, and off the shelf pumps may be used, whether centrifugal, jet-type or submersible. This system provides "removed" capability, getsf around high cut-in speed with battery storage, and used the pump

		efficiently by driving it at a constant speed. This concept is not new (eg North Wind has put similar packages together) but the Canadian application of it, sized and designed for our use, is.
46	Maestro label (dk black)	Nor'wester's design is called the MAESTRO.
47	Maestro at Lethbridge	It has recently been installed at Lethbridge, and only manual data are available to date.
48	Bergey 1000 lying down	We use a modern rugged low maintenanceturbine, in this case a Bergey 1000 watt unit.
49	Tower during raise	It is installed on a tilt tower of our own design and manufacture.
50	Winch system	Raised with a winch system.
51	Controls & batteries, Tech	The PowerHouse contains controls, batteries, inverter and at this site a 1/2 hp Monarch pump. This system also provides additional 120 VAC outlets for the use of tools at the site - very handy for farmers and ranchers, and potentially useful for 3rd world applications.
52	Far view of system (down)	This is another view of the system, tilted down.
53	Fuzzy shot of water pipe	A rather fuzzy view of the water being pumped out of the outflow pipe; our measurements at the site at 6 m lift indicate constant flows of 45 gpm or about 3.5 litres/sec.
54	Graph of MAESTRO rates	Of course, with battery storage, so long as sufficient wind is present to mainatin charge, the system will pump at full capacity even with no wind, or while the tower is tilted down for inspection.
55	Graph of Maestro & others	This graph compares the MAESTRO to findings shown earlier for small flow water pumpers.
56	View of MAESTRO System	This view shows the entire system, with the Power House on the right.
57	Nice view of Lethbridge site	The Lethbridge test site has certainly assisted the creativity and development of this technology in Canada, particularly in Alberta. Domestic sales, from site visits and demonstration days, are beginning to take off. Foreign sales have not yet occured to any great extent, but the interest is high. We have received enquiries from the Arab states, Africa, Caribean, India and the USA. In particular, all these systems hold promise for 3rd world applications, especially Buck Massey's and John Kentfields's inexpensive, effective systems. We at Nor'wester hope that the double provision of water, and electricity, will gain us a market niche there, too.
58	Jason riding away	Well, I hope that you enjoyed this presentation, and that the technology of tape recorder and projector worked well. I've got some chores to attend to - like watching those mountains, listening to my windplant hum, and (oh yes) preparing the baby's new room!
59	Company name	Perhaps I'll see you in Calgary, real soon.
60	Blank slide	

OPTIMIZATION OF WIND PUMPING RESERVOIR CAPACITY

E. J. Schiller and U. D. Assam
Department of Civil Engineering
University of Ottawa, Canada

ABSTRACT

The derivation of a computer program to determine the optimum size of a storage reservoir for a wind-powered water pumping system is described. The program is for a multi-bladed horizontal axis windmill connected to a reciprocating pump. The program can use either measured wind characteristics or statistical wind distributions (Weibull or Rayleigh). The inputs are wind turbine, wind pump and well characteristics and user demand levels. The output is presented as storage-yield curves as a function of different reliability levels.

INTRODUCTION

Wind pumping systems are used worldwide especially in developing countries, and in remote areas in industrialized countries. Because of the variability of the wind, if water is to be supplied during periods of little or no wind, it becomes necessary to provide a storage facility. A diagram of a typical wind-powered water pumping system is given in Fig. 1.

A storage model for multi-bladed water pumping turbines coupled to piston pumps has recently been developed for use on computers. The complete description and development of the model are described elsewhere [2]. Given the wind turbine, wind, pump and well characteristics, storage-yield functions can be computed for different reliability levels.

The model was tested using data from a Dempster wind turbine assumed to operate in the wind regime of Ottawa International Airport, using actual wind data and two assumed wind speed distributions. The Weibull distribution was found to approximate the actual distribution more closely than the Rayleigh distribution. It was found that the Weibull and Rayleigh distributions overestimated the storages when compared to the actual distribution.

WIND TURBINE CHARACTERISTICS

The energy available in the wind, P_w, is:

$$P_w = (1/2)\ \rho_o\ AV^3 \qquad (1)$$

where A = rotor swept area
V = wind speed
ρ_o = air density

The shaft power, P_s, at the turbine is given by:

$$P_s = (1/2)\ \rho_o A V^3 C_P \qquad (2)$$

where C_P = power coefficient

The average shaft torque provided by the wind turbine, after accounting for the gear ratio and gear efficiency [3], is:

$$T_q = (1/2)\rho_o V^2 A(D/2)C_q G_r \eta_t \qquad (3)$$

where C_q = torque coefficient
D = rotor diameter
T_q = rotor torque
G_r = gear ratio
η_t = gear efficiency

Different researchers have developed models for computing the output of multi-bladed wind turbines. The model of Wyatt and Hodgkin [3] is based on the average load torques of the pump and wind turbine, using a linear relationship between the torque coefficient and the tip-speed ratio. In this development, a parabolic relationship between C_P and the tip-speed ratio (TSR) [4], and a linear relationship between C_q and TSR [3] are assumed.

$$C_P = \overset{C_{pm}-}{\wedge} C_{Pm}[(\lambda-\lambda_d)/(\lambda_m-\lambda_d)]^2 \ ; \ \lambda_{qm} < \lambda < \lambda_m \qquad (4)$$

$$\lambda = \lambda_m - \lambda_m(C_q/C_{qm}) \qquad (5)$$

where

$$\lambda_{qm} = \sqrt{[\lambda_m(2\lambda_d-\lambda_m)]} \qquad (6)$$

$$C_{qm} = -2C_{pm}[(\lambda_{qm}-\lambda_d)/(\lambda_m-\lambda_d)^2] \qquad (7)$$

$$\lambda = U/V \qquad (8)$$

C_{pm} = maximum power coefficient
C_{qm} = maximum torque coefficient
U = rotor tip speed
λ = TSR
λ_d = design TSR
λ_m = maximum TSR
λ_{qm} = TSR at maximum torque coefficient.

PUMP CHARACTERISTICS

The mechanical power required by the pump to lift the flow, Q, through a head, H, is:

$$P_m = \gamma_w H\ Q/\eta_m \tag{9}$$

where P_m = mechanical power
γ_w = specific weight of water
η_m = mechanical efficiency of the pump

The rate of water pumped is directly proportional to the stroke rate of the pump and hence the rotational speed of the wind turbine ([2], [3] and [5]).

$$Q = \eta_v(\pi/4)D_p^2 S(\Omega/2\pi) \tag{10}$$

where

$$\Omega = 2\lambda V/(DG_r) \tag{11}$$

D_p = pump diameter
S = pump stroke
η_v = volumetric efficiency of pump
Ω = rotational speed of pump shaft

Combining Eqns. (9) and (10), the mechanical power is given as:

$$P_m = T_w\Omega \tag{12}$$

where

$$T_w = \eta_v\gamma_w D_p^2 SH/(8\eta_m) \tag{13}$$

T_w = average water load torque

WIND CHARACTERISTICS

Any one of the following three different types of wind distributions can be used depending on the availability of data and parameters:

1. Actual distribution: this depicts the speed-frequency values which give the relationship between the time the wind blows at a particular wind speed interval.
2. Weibull distribution

$$p(V) = (k/c)(V/c)^{k-1}\exp[-(V/c)^k] \tag{14}$$

where
c = scale parameter
k = shape parameter
$p(V)$ = probability density function

3. Rayleigh distribution

$$p(V) = (\pi/2)(V/\overline{V}^2) \exp[-(\pi/4)(V/\overline{V})2] \qquad (15)$$

where

$\overline{V}$ = average wind speed.

STORAGE

By equating the average water load torque to the rotor torque, the pumping curve can be derived. The pumping curve gives the relationship between the wind turbine discharge against wind speed. The volume of water pumped is computed by integrating the pumping curve over the wind histogram. This calculated volume is then used as the reservoir input, and the storage can be determined at different reliability levels using the following algorithm given by McMahon and Mein (4):

1. Choose a reservoir of capacity, C, and assume that it is full at the beginning.
2. Apply Eqn. (16) period by period for the whole record, D_t being assumed to be constant.
3. Compute the time-based reliability using Eqn. (17).
4. If the reliability is unacceptable, choose another value of C and repeat the procedure.

$$S_{t+1}/\Delta t = S_t/\Delta t + Q_t - D_t \; ; \quad 0 < S_{t+1} < C \qquad (16)$$

$$Rel = 1 - \Sigma\Delta t_f/T \qquad (17)$$

where

D_t = demand at beginning of period t
Q_t = inflow at beginning of period t
S_t = storage at beginning of period t
S_{t+1} = storage at beginning of period t+1
Δ_t = duration of a single time period
Δ_{t_f} = duration of a single failure period
T = total time period
Rel = reliability

TESTING OF MODEL

The model developed was used to simulate a Dempster wind turbine, assumed to be installed at the Ottawa International Airport, and coupled to a piston pump (Table 1). The pumping curve for the chosen wind turbine is shown in Fig. 2.

Wind speed data for 32 years were used to derive the wind histograms for the assumed site. The storage capacities calculated for the given wind regime are shown in Fig. 3 for three different wind speed distributions. Fig. 4 shows the storage-yield functions at different reliability levels. Sensitivity analyses where also done on some of the important input parameters (C_{pm}, G_r, η_m and η_v) to the computer program.

CONCLUSION

A computer program has been developed to assist users to accurately determine the optimal reservoir storage to supply water with a given reliability for wind power pumping systems. A flow chart of the main program is given at the end of the paper.

Given the wind turbine, pump, wind and pumping characteristics, a curve similar to Fig. 4 can be derived. On the basis of these derived curves, an optimal storage size can be rapidly determined for the above parameters if the water demand and the desired reliability are known.

For example, if the water demand is 15 m^3/day and 90% reliability is sufficient, then the reservoir storage required is 50 m^3. However, if 100% reliability is desired, then 400 m^3 reservoir storage capacity is required.

REFERENCES

1. Johnson, G.L. 1985, Wind Energy Systems, Prentice-Hall, New Jersey.
2. Assam, U.D. 1986. "Storage Model for Multibladed Water Pumping Windmills with Piston Pumps", M.A.Sc. Thesis, Department of Civil Engineering, University of Ottawa, Canada.
3. Wyatt, A.S. and Hodgkin, J., "A Performance Model for Multibladed Water Pumping Windmills", V.I.T.A., Virginia.
4. McMahon, T.A. and Mein, R.G. 1978. Development in Water Science 9: Reservoir Capacity and Yield, Elsevier Scientific, New York.
5. Bragg, G.M. 1982. "Wind-Power Pumping", Water Supply and Sanitation in Developing Countries (E.J. Schiller and R.L. Droste, Eds.), Ann Arbor Science, Chap. 6, pp.65-84.
6. Lysen, E.H. 1982. Introduction to Wind Energy, Consultancy Services Wind Energy in Developing Countries (CWD), Amersfort, The Netherlands.
7. Pinilla, A.E. et al., 1984. "Wind Energy to Water Pumped: Conversion Efficiency Limits Using Single-Acting Lift Pumps", 6th BWEA Conference, Reading, U.K.

TABLE 1

Windmill and Pump Characteristics

Windmill

Type: multibladed

Model: #12

Diameter = 3.7 m

Gear ratio = 3:1

Number of blades = 18

Cut-in speed = 2.2 m/s

Rated speed = 8.5 m/s

Cut-out speed = 22 m/s

C_{pm} = 0.30; ref. [7]

λ_d & λ_m = 1 and 2 respectively; ref. [3]

η_t = 0.90; ref. [3]

PUMP

Type: piston

Diameter = 0.10 m

Stroke = 0.30 m

η_m & η_v = 0.60 & 0.90 respectively; ref. [3]

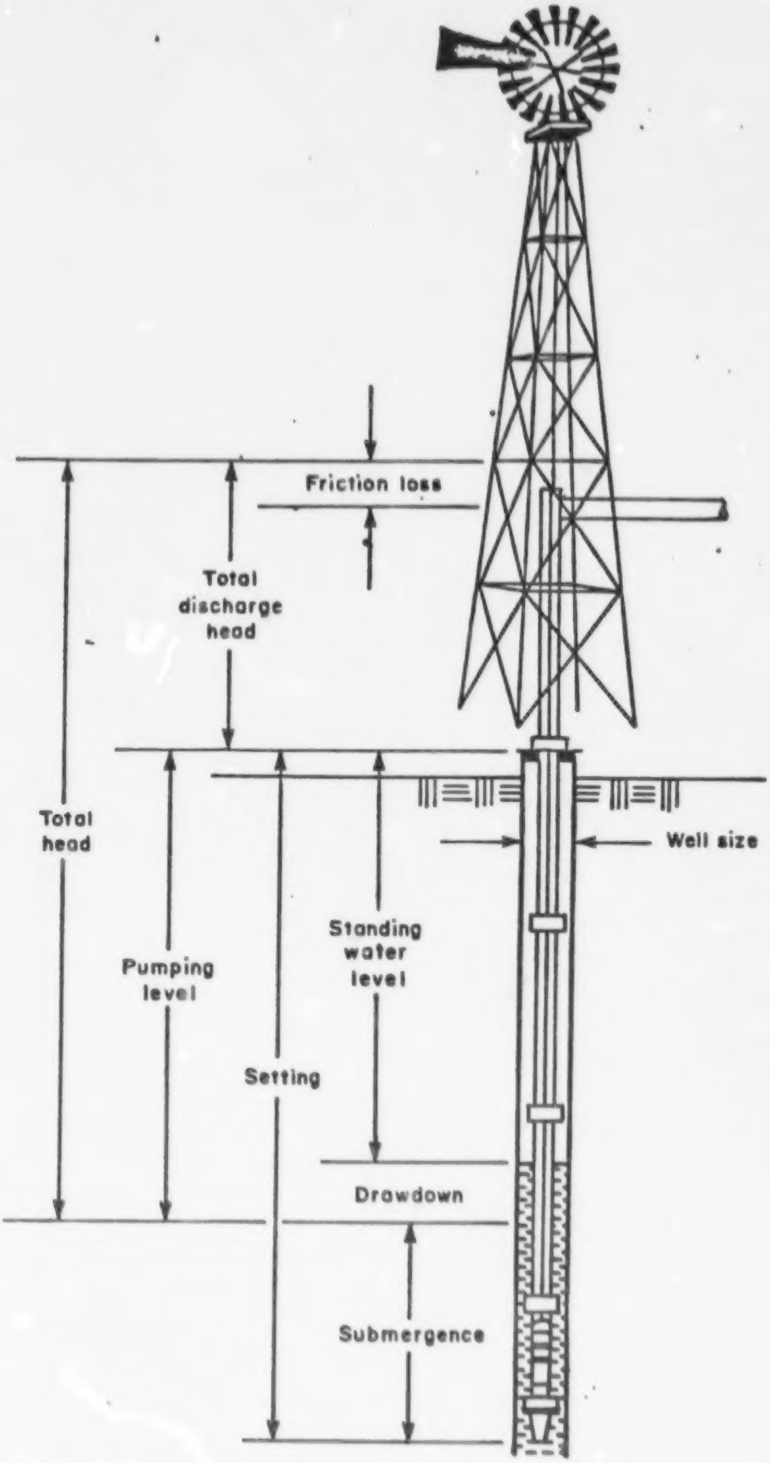

Friction loss
Total discharge head
Total head
Well size
Standing water level
Pumping level
Setting
Drawdown
Submergence

Figure 1: Wind power pumping system [1]

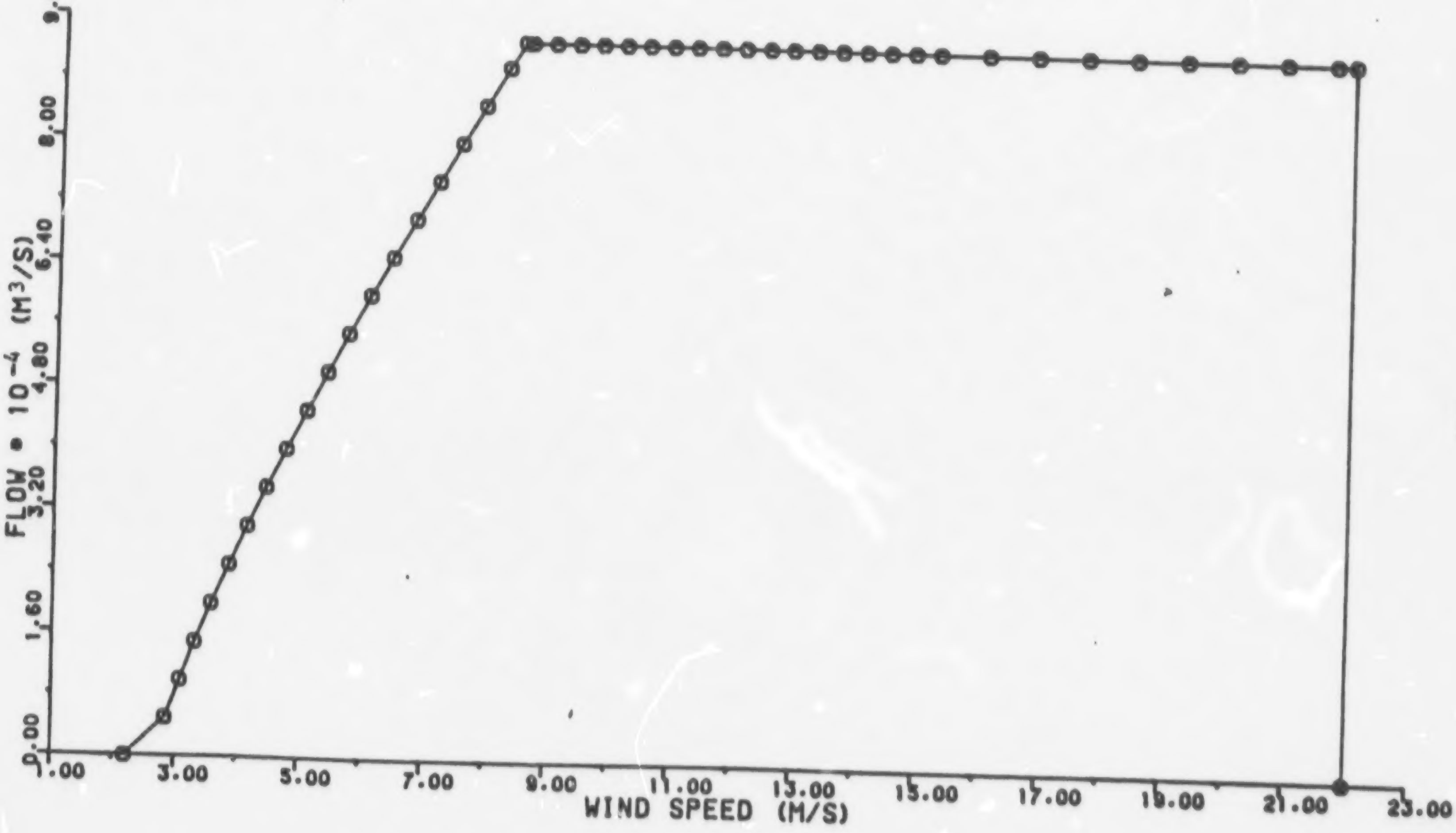


Figure 2: Instantaneous windmill output (flow) versus wind speed

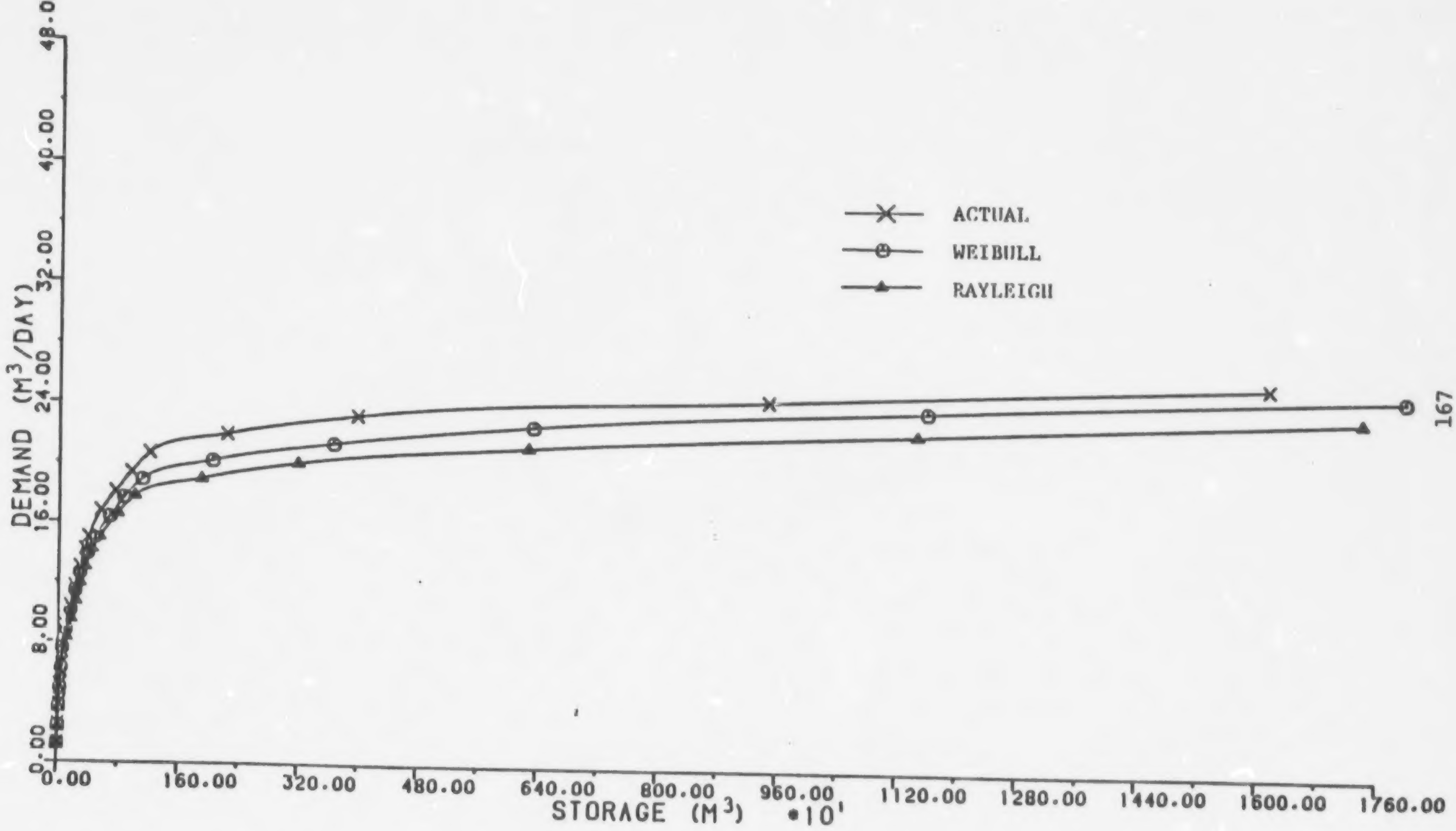


Figure 3: Storage-yield functions at 100% reliability for actual, Weibull and Rayleigh wind speed (daily) distributions

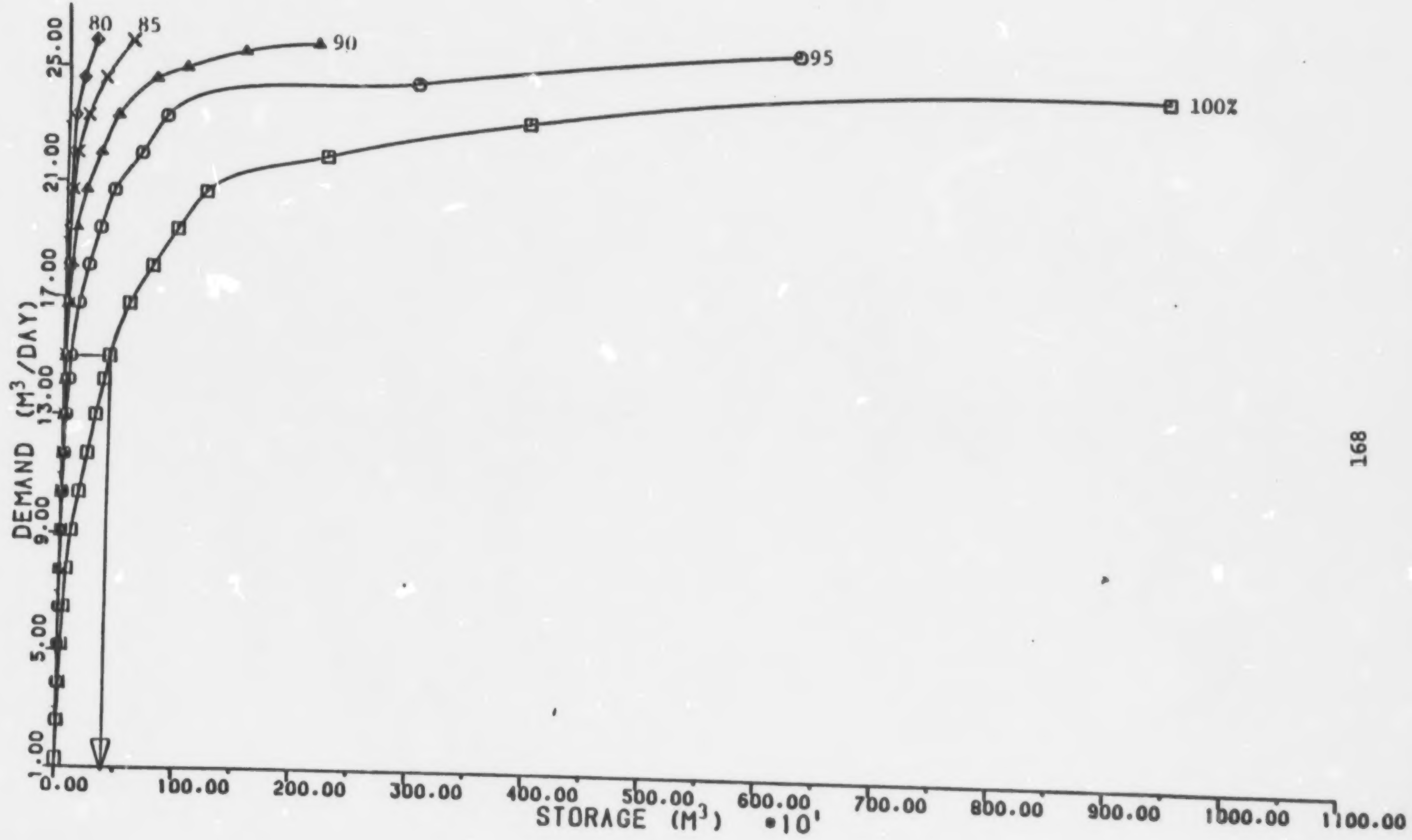
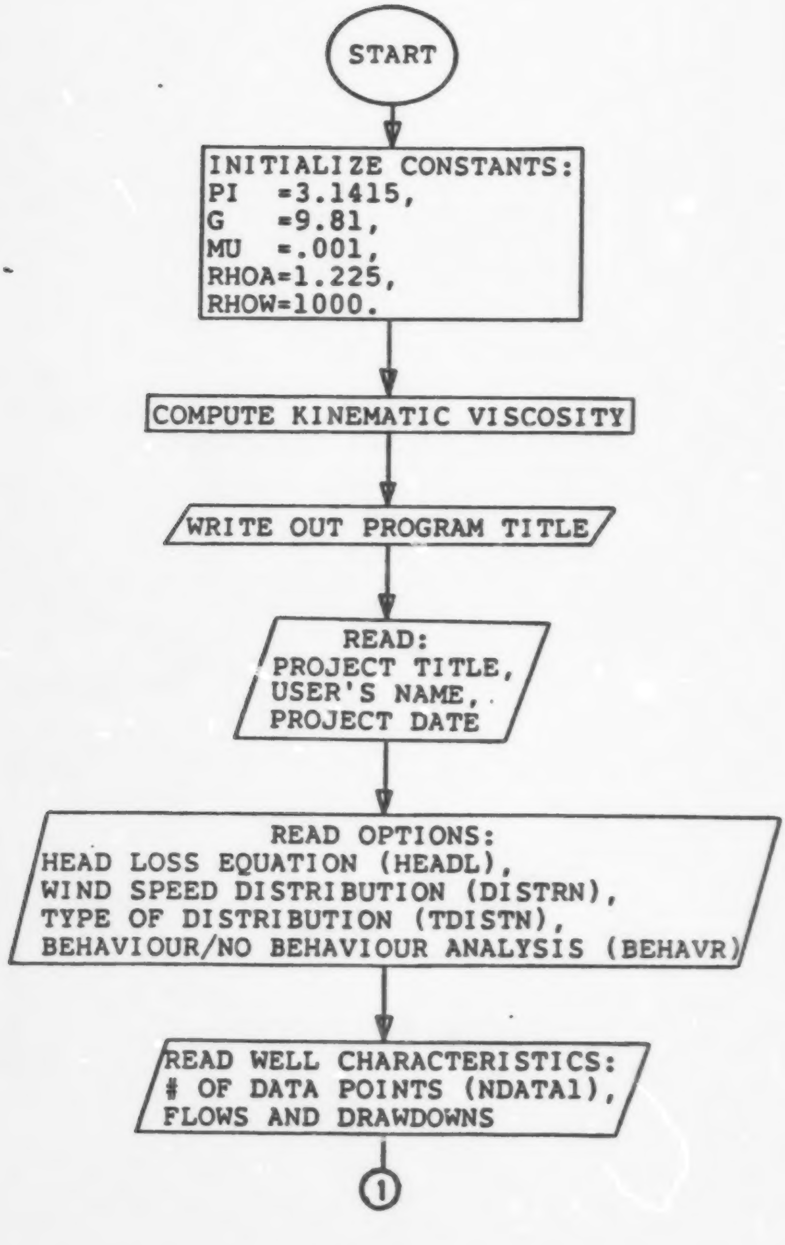


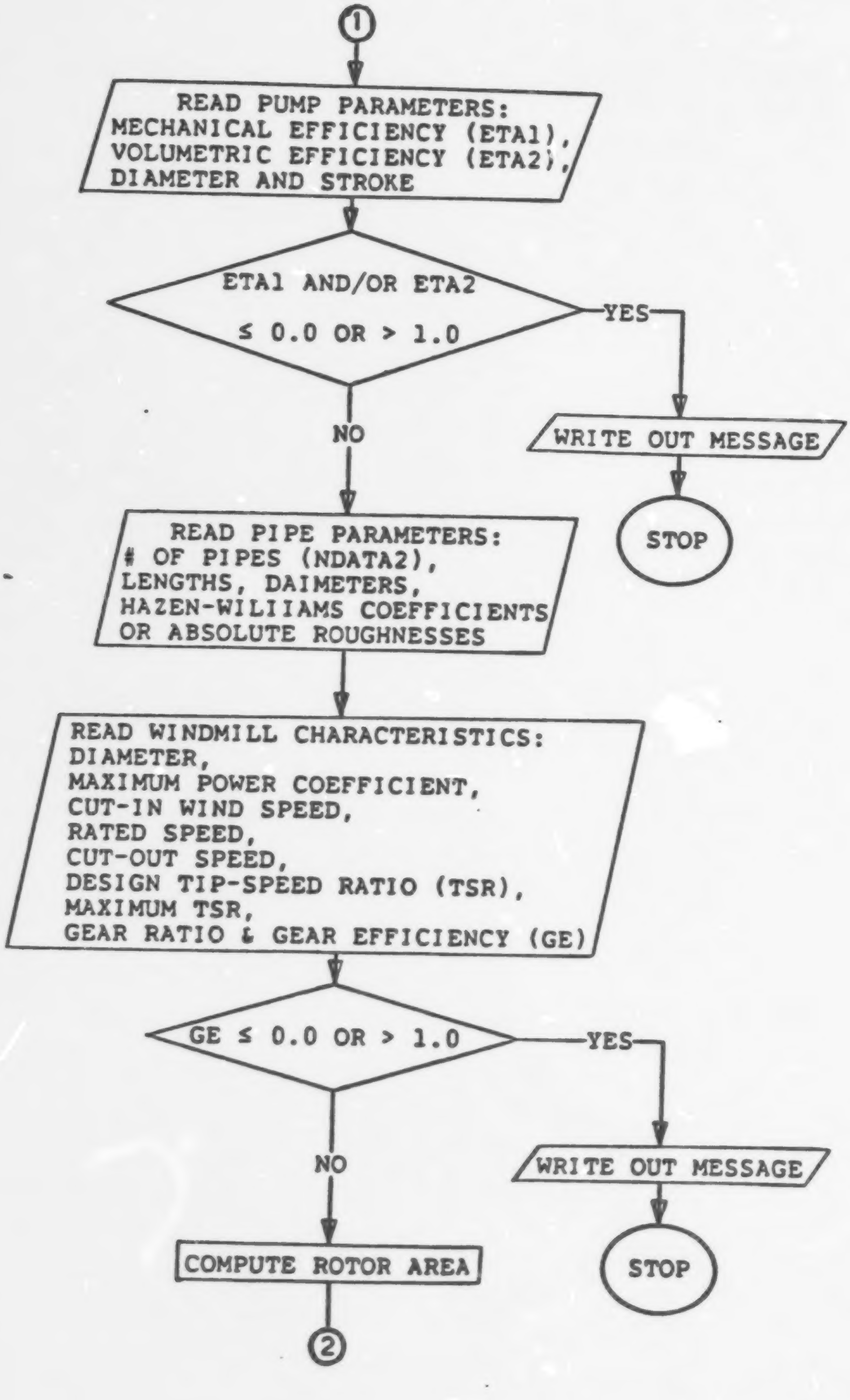
Figure 4 : Storage-yield functions at different levels of time-based reliability for actual wind speed (daily) distributions

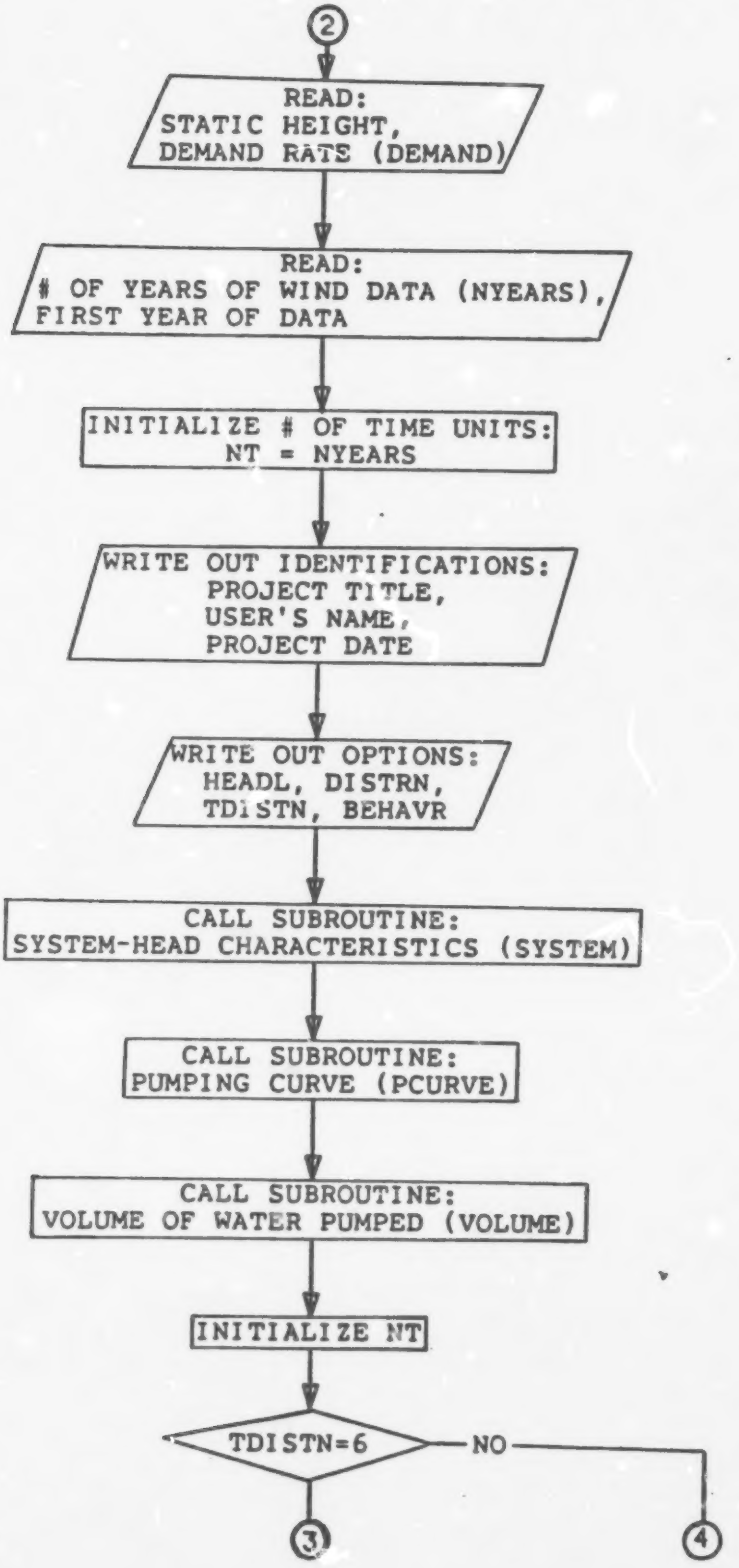
Appendix A

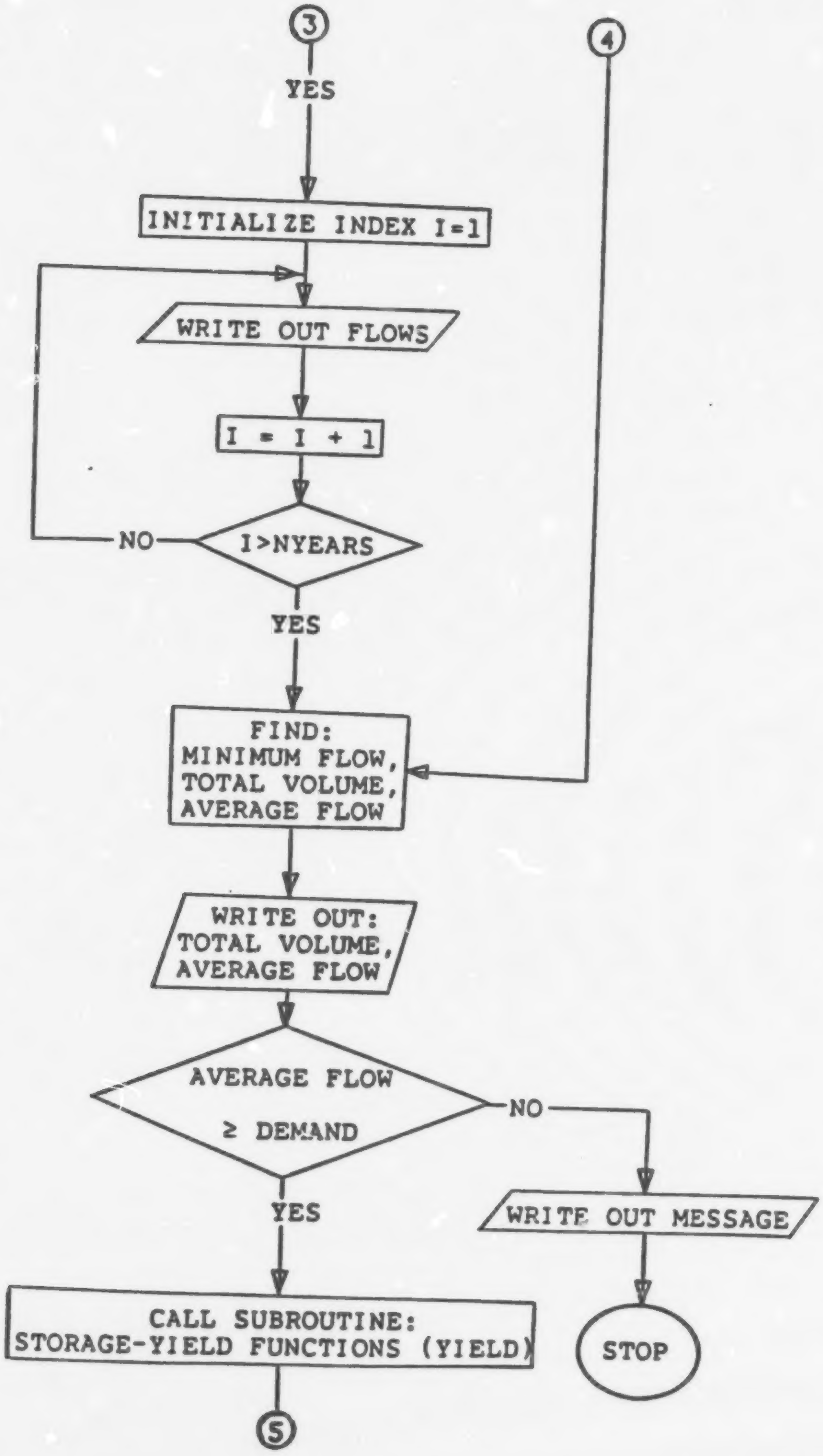
FLOWCHARTS

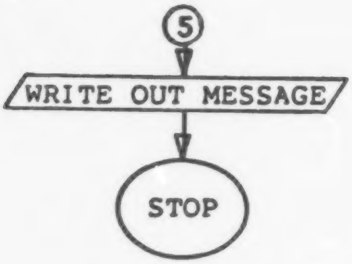
MAIN PROGRAM


START
INITIALIZE CONSTANTS:
PI =3.1415,
G =9.81,
MU =.001,
RHOA=1.225,
RHOW=1000.
COMPUTE KINEMATIC VISCOSITY
WRITE OUT PROGRAM TITLE
READ:
PROJECT TITLE,
USER'S NAME,
PROJECT DATE
READ OPTIONS:
HEAD LOSS EQUATION (HEADL),
WIND SPEED DISTRIBUTION (DISTRN),
TYPE OF DISTRIBUTION (TDISTN),
BEHAVIOUR/NO BEHAVIOUR ANALYSIS (BEHAVR)
READ WELL CHARACTERISTICS:
# OF DATA POINTS (NDATA1),
FLOWS AND DRAWDOWNS
1


1
READ PUMP PARAMETERS:
MECHANICAL EFFICIENCY (ETA1),
VOLUMETRIC EFFICIENCY (ETA2),
DIAMETER AND STROKE
ETA1 AND/OR ETA2
≤ 0.0 OR > 1.0
YES
WRITE OUT MESSAGE
STOP
NO
READ PIPE PARAMETERS:
# OF PIPES (NDATA2),
LENGTHS, DAIMETERS,
HAZEN-WILIIAMS COEFFICIENTS
OR ABSOLUTE ROUGHNESSES
READ WINDMILL CHARACTERISTICS:
DIAMETER,
MAXIMUM POWER COEFFICIENT,
CUT-IN WIND SPEED,
RATED SPEED,
CUT-OUT SPEED,
DESIGN TIP-SPEED RATIO (TSR),
MAXIMUM TSR,
GEAR RATIO & GEAR EFFICIENCY (GE)
GE ≤ 0.0 OR > 1.0
YES
WRITE OUT MESSAGE
STOP
NO
COMPUTE ROTOR AREA
2


2
READ: STATIC HEIGHT, DEMAND RATE (DEMAND)
READ: # OF YEARS OF WIND DATA (NYEARS), FIRST YEAR OF DATA
INITIALIZE # OF TIME UNITS: NT = NYEARS
WRITE OUT IDENTIFICATIONS: PROJECT TITLE, USER'S NAME, PROJECT DATE
WRITE OUT OPTIONS: HEADL, DISTRN, TDISTN, BEHAVR
CALL SUBROUTINE: SYSTEM-HEAD CHARACTERISTICS (SYSTEM)
CALL SUBROUTINE: PUMPING CURVE (PCURVE)
CALL SUBROUTINE: VOLUME OF WATER PUMPED (VOLUME)
INITIALIZE NT
TDISTN=6
NO
3
4


3
4
YES
INITIALIZE INDEX I=1
WRITE OUT FLOWS
I = I + 1
NO
I>NYEARS
YES
FIND:
MINIMUM FLOW,
TOTAL VOLUME,
AVERAGE FLOW
WRITE OUT:
TOTAL VOLUME,
AVERAGE FLOW
AVERAGE FLOW
≥ DEMAND
NO
YES
WRITE OUT MESSAGE
CALL SUBROUTINE:
STORAGE-YIELD FUNCTIONS (YIELD)
STOP
5


5
WRITE OUT MESSAGE
STOP

A TWIN-AIRFOIL TYPE, OSCILLATING BEAM, WIND-DRIVEN WATER PUMPER

J.A.C. Kentfield[*], M. Booth[+] and D. Horsley[+]
Department of Mechanical Engineering
University of Calgary
Calgary, Alberta, Canada

ABSTRACT

Results are presented of wind-tunnel tests carried out on a fully functional, load-pump equipped, working model of a twin-airfoil oscillating beam water pumper. The test results indicate that the machine works well and that the upwind aerodynamic surface, or canard, serves to inhibit stalling in weak winds. A full-scale prototype machine was also constructed. Preliminary test results show that this unit functions much in accordance with predictions but that an improved performance should be achievable after some development. It was found that the projected improved full-scale performance, whilst inferior to that of more conventional rotary type wind driven water pumpers of comparable size, appears to be adequate for a number of applications. The inherent advantages of oscillating beam water pumpers are perceived to be; simplicity, ease of maintenance, a low projected first cost and low frequency operation which permits these devices to be directly coupled, without an intermediate speed reducer, to reciprocating deep-well pumps.

NOMENCLATURE

C_D	Drag coefficient
C_L	Lift coefficient
$C_{L(EFF)}$	Effective lift coefficient (based on mainplane area)
D	Chord of mainplane (also Drag)
L	Lift
M	Mass ratio: mass per unit area/(Mass per unit area of model) S^3
r	Radius of action
R	Radius of mainplane pivot (see Fig. 8)
S	Scale (i.e. multiple of model dimension)
U_∞	Wind speed at beam pivot height
W	Weight (see Fig. 8)
X_{CP}	Distance of centre of pressure from leading edge (fraction of chord)
α	Incidence angle
β	Downwash angle due to canard
γ	Yaw angle (see Fig. 11)
θ	Blade tilt angle (±25°)
ϕ	Inclination of beam

Subscripts

CPC	Centre of pressure of canard

---

[*] Professor [+] Student

CPM	Centre of pressure of mainplane
DC	Drag, canard
DM	Drag, mainplane
LC	Lift, canard
LM	Lift, mainplane
C	Canard
M	Mainplane

INTRODUCTION

The oscillating beam type wind-driven water pumper, sometimes referred to as an aeolian pumpjack (1), is intended for use primarily in developing nations. The machine is designed in such a way that it can be built, indigenously, from materials likely to be readily available in a developing nation. Only a very modest facility is required for manufacture, such as a small workshop of the type which may well be in existence. The apparatus can be constructed without the need for machining etc. other than a means of drilling holes; some welding and a little foundry work are also required. Ease of transportation, erection and maintenance were other factors taken into account in order to minimise costs and infrastructure requirements. The maintenance consideration included access to the pump: to this end a free standing space-frame type tower was selected since this structure provides a convenient support for a block-and-tackle to withdraw the pump for servicing.

An inherently low frequency of operation was considered to be another important attribute of the oscillating concept since this permits the apparatus to be used for deep-well pumping if need be. Deep-well reciprocating water pumps normally depend upon gravity for the return stroke of the pump-plunger hence the maximum permissible acceleration of the pump-plunger is much less than that due to gravity. Because of the low frequency, and consequently the low accelerations involved, it is feasible to connect a deep-well pump directly to the oscillating beam without any intermediate speed reducer.

The device described here differs from earlier oscillating beam type wind-driven water pumps in that two airfoil surfaces are employed one being a canard-like surface rigidly attached to the upwind end of the free-yaw oscillating beam, the other a tilting mainplane attached to the downwind end of the beam. Prior oscillating beam wind-driven pumps were not, so far as the writers are aware, provided with a canard surface. The purpose of the canard surface is to inhibit stalling of the machine during weak-wind operation. The wind tunnel tests reported here serve to verify the perceived functioning of the canard and to quantify the operational characteristics of the system. It should, however, be noted that an oscillating beam system using two conventional, relatively high aspect ratio, wings of approximately equal span mounted at opposite ends of a lattice type beam was tested, briefly, in Kansas in 1982 (2). The Kansas machine, which employed electronically controlled servo tabs, or flaps, to pitch both the fore-plane and the aft-plane, was intended for electrical power production.

OPERATING PRINCIPLE

Figure 1 is a photograph of the pump-equipped fully functional wind-tunnel model of the oscillating beam pumper. The chord of the main, downwind,

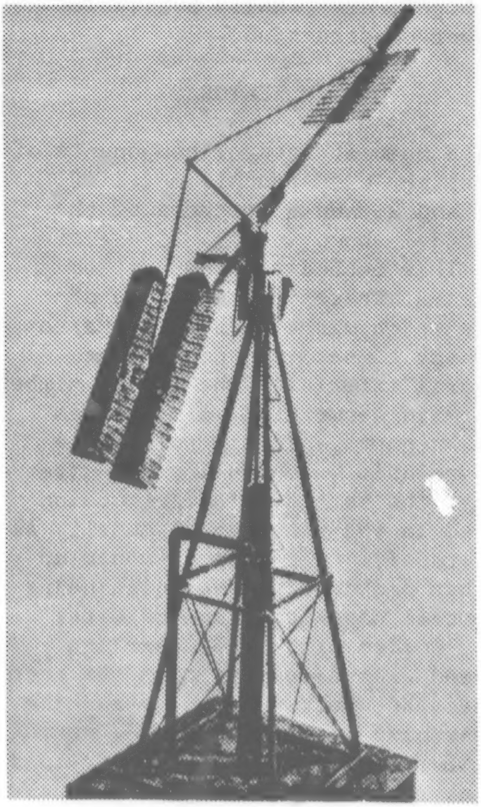


FIG. 1 WORKING MODEL: MAINPLANE ABOUT TO ASCEND

airfoil of the model is 203 mm (8 in); the beam pivot height is 642 mm (25.3 in) above the simulated ground surface. It can be seen that wind acting on the large, downwind, tilting airfoil, or mainplane, causes the downwind end of the beam to rise due to the combined influence of lift and drag. This motion is opposed by the foreplane or canard. After the beam has passed through the horizontal position the foreplane serves to assist the beam motion raising yet further the downwind end of the oscillating beam. After the downwind end of the oscillating beam has risen sufficiently to present the mainplane at zero incidence relative to the oncoming flow the mainplane "flips" thereby resulting in driving downwards the downwind end of the oscillating beam. The configuration of the machine immediately prior to mainplane "flip" is shown in Fig. 2. An alternative and somewhat more detailed description of the operation of the twin-airfoil canard type oscillating beam system is available as part of a preliminary study of the concept (1).

By careful selection of the relative position along the beam of the canard and mainplane surfaces, and by the use of low aspect-ratios, it will later be shown that it is possible to achieve, under very low speed conditions such as prevail at start up, an approximately uniform load on the pump rod. In fact, since pumping only occurs on the upstroke of the pump rod, the oscillating beam should be heavier, at the mainplane end, to an extent which corresponds to half the pumping load. By this means work is extracted from the system on both strokes of the oscillating beam when only a simple, single acting, lift pump is used. Hence, at very low operating speeds, work is done against gravity on the upstroke of the mainplane whilst, on the downstroke, only half of the force needed to operate the pump is generated aerodynamically; the remainder is due to gravity.

The working model shown in Fig. 1 and 2 reflects, as far as is possible in a fairly small scale, methods of fabrication which are likely to be employed in a relatively small full-scale unit. Another very small-scale working model is shown in Fig. 3; this model, which is provided with a dummy pump only, has a mainplane chord of 51 mm (2 in); it differs from the larger model of Fig. 1 and 2 primarily in that a tripod type tower is employed in conjunction with a beam of relatively large cross-section which is not reinforced by a king-post and tie-bar. A tripod tower can be convenient when round cross-section timbers, or water pipes, are readily available for tower construction.

DESIGN FEATURES

The main structural components of the working, wind-tunnel, model of Fig. 1 and 2, and also those of the small model shown in Fig. 3, are of wood. This method of construction represents, therefore, the type of machine which might be built in a region where timber is a convenient structural material. The use of timber as the main structural material was used subsequently in the full scale prototype unit which followed, quite closely, the methods of construction employed in the wind-tunnel model. As an alternative to timber it would appear that machines can be built using light steel angle sections or water pipes. Wooden block type bearings were used exclusively in both the models and the subsequent full scale machine. Wood was also used as a bearing material for both vertical and side-load surfaces in the yaw bearing at the tower top for all three units.

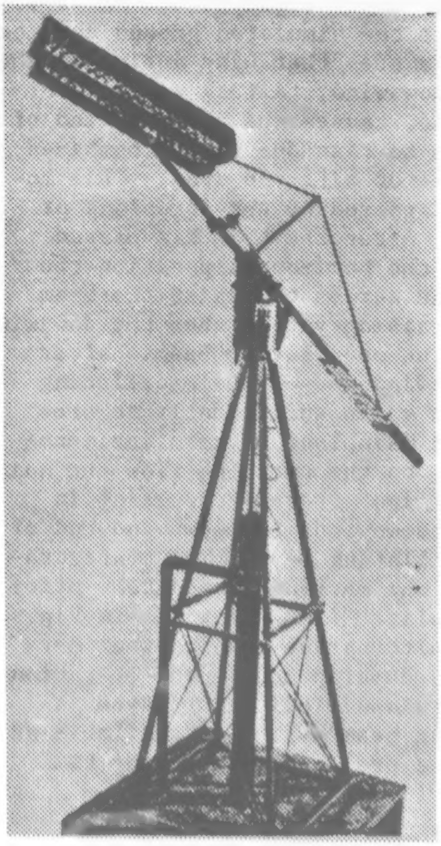


FIG. 2 WORKING MODEL: MAINPLANE TILTING PRIOR TO DESCENT

A combination of the requirement that the machine utilise only very simple, easily fabricated, aerodynamic surfaces plus the desirability of employing a long-stroke, relatively small bore, pump suggested the use of low aspect ratio aerodynamic surfaces. Low aspect ratios permit the use, with very little additional performance loss, of flat plate rather than airfoil cross-section blades. Further the very high stall angles, and gentle stall characteristics, of low aspect ratio surfaces are conditions consistent with large angular movement of the oscillating beam and hence a long pump stroke. Accordingly an aspect ratio of essentially unity was selected for the mainplane. The resultant proportions of the unit, as established on the basis of wind-tunnel testing, are shown in Fig. 4. The permitted tilt of the mainplane relative to the oscillating beam is ±25°. The chord, D, of the mainplane was 203 mm (8 in) for the wind-tunnel model; the prototype full scale unit was twelve times larger. The use of transverse corrugations in the airfoils, as apparent from Fig. 1, 2 and 3, was for structural reasons. The proportions of the corrugations are shown in the upper left-hand corner of Fig. 4. Corrugated, galvanised, steel sheet is a commonly available material used in building construction. Naturally the use of transverse corrugations can be expected to impose an additional performance loss over and above those due to low aspect ratio and (essentially) flat plate surfaces.

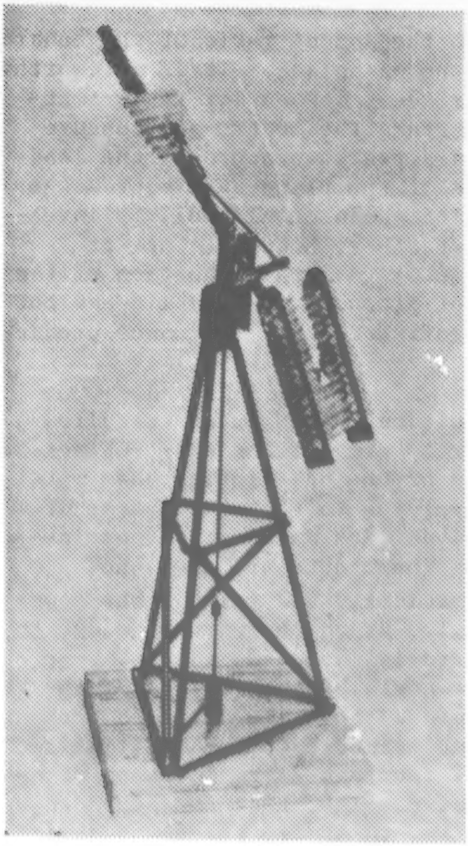


FIG. 3 SMALL WORKING MODEL WITH TRIPOD TOWER

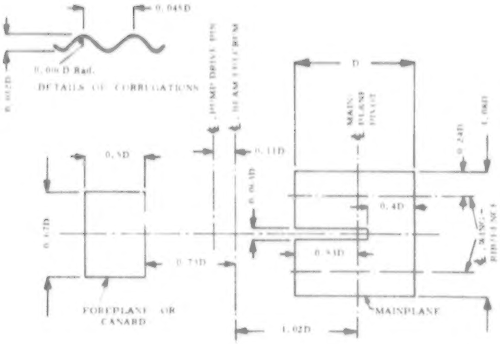


FIG. 4 GEOMETRY OF OPTIMISED CONFIGURATION

WIND-TUNNEL TESTS OF MODEL

Tests in a wind-tunnel equipped with a lift-and-drag balance were carried out on representative canard and mainplane model surfaces. Both flat plate and corrugated flat plate surfaces were tested and, in the case of the mainplane, with and without central beam-clearance slots (see Fig. 4) and with and without the external ribs, apparent in Fig. 1, 2 and 3, needed as chordwise stiffeners. The final results obtained for the mainplane and the canard, as corrected for tunnel blockage, etc. are shown in Fig. 5 and 6 respectively. The aspect ratio of the canard was treated as a variable which was derived from wind-tunnel tests of the full oscillating beam assembly which was equipped with a number of alternative canard surfaces. The aim of the tests of the full beam assembly was to achieve a uniform force, at essentially static conditions, acting on the pump rod over the full angular range of movement of the oscillating beam.

It can be seen from Fig. 5 and 6 that for angles of incidence, α, up to about 25° transverse corrugations result, as might be expected, in increased drag with little influence on lift. For angles of incidence greater than 25° the lift is reduced due to the corrugations, the reduced lift also results in an overall drag reduction despite the roughness of the corrugated surface. In order to predict the static (i.e. start-up) performance of the oscillating beam pumper from knowledge of Fig. 5 and 6 it is also necessary to know the location of the centres of pressure of both the canard and the mainplane as functions of incidence angle. Figure 7 is an experimentally obtained plot, versus α, of the fraction of the chord aft of the leading edge, X_{CP}, at which the centre-of-pressure is located for low aspect ratio smooth, flat surfaces. No perceptible difference was identified between plates having aspect ratios

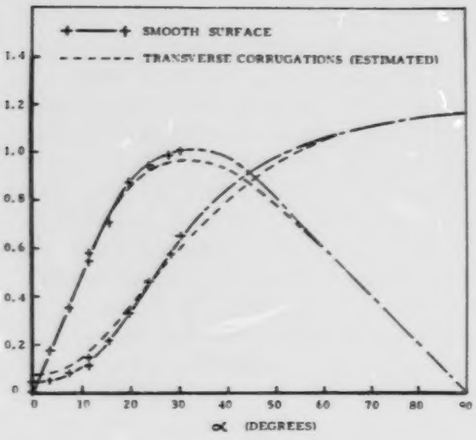


FIG. 5 LIFT AND DRAG COEFFICIENTS OF MAINPLANE

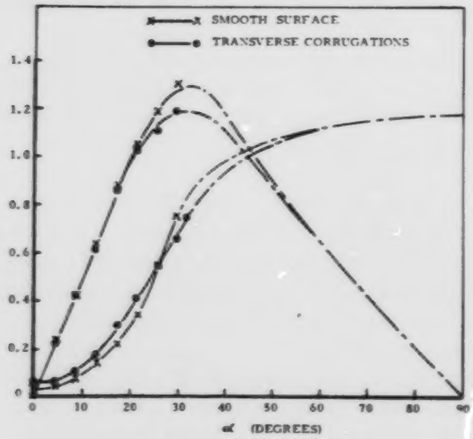


FIG. 6 LIFT AND DRAG COEFFICIENTS OF CANARD

equal to the aspect ratio of the canard and of the mainplane. It is noteworthy that for these low aspect ratio flat-plate surface the centre-of-pressure location appears to approach the leading edge of the plate as α approaches zero. This point could well be investigated further; however, lack of knowledge of the exact location of the centre-of-pressure for small α has but little influence on performance prediction.

Additional information required in order to predict the start-up performance of the oscillating beam water pumper relates to the moment arms of the various lift and drag forces involved. These data are presented diagrammatically in Fig. 8. The downwash angle, β, on the mainplane due to the canard is indicated in Fig. 8: ϕ is the angle of inclination of the beam and θ is the tilt angle of the mainplane relative to the oscillating beam. W represents the location of an over-centre weight that can be added, if need be, to modify the aerodynamic characteristics of the system. For the model oscillating beam unit θ = ±25°. Stops impose a mechanical limitation on ϕ of ±54° with an expectation that for most operating conditions ϕ will lie within the range ±45°, or less, the angular stroke of the oscillating beam being thus controlled entirely by aerodynamics in collaboration with the dynamics of the system and not by impacting the mechanical stops which determine the absolute maximum and minimum values of ϕ.

Predicted performances at start-up conditions are shown in Fig. 9 (solid lines) these results being based on individual airfoil characteristics. Two separate conditions are represented in Fig. 9, one in which the foreplane is removed, and hence only the mainplane is used and the condition of most interest employing both the foreplane, or canard, and the mainplane. The ordinate of Fig. 9 is the effective lift coefficient of the system, referred to the planform area of the mainplane, and is, therefore, a parameter directly proportional to the force acting on the pump rod. The portion of the predicted curve lying between ϕ = -25° and ϕ = -54° is of academic interest in that it shows the expected performance with the foreplane only operational; "flip-over" of the mainplane should begin to occur at ϕ = -25°. The dotted curves of Fig. 9 represent the directly measured results for the

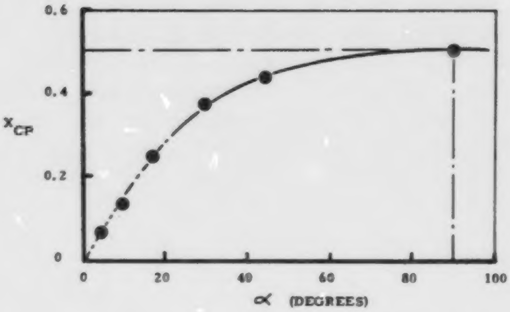


FIG. 7 APPROXIMATE LOCATION OF CENTRE-OF-PRESSURE VERSUS INCIDENCE ANGLE

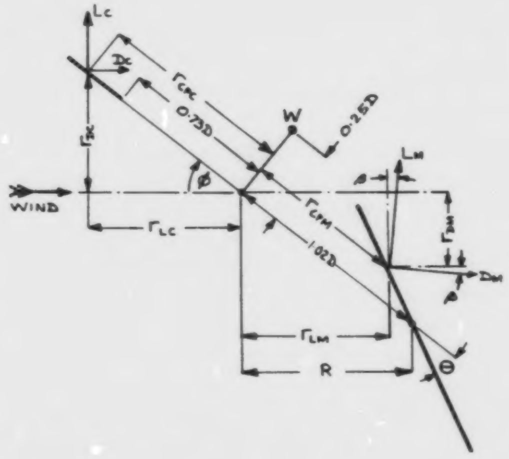


FIG. 8 SYSTEM FORCES, MOMENT ARMS ETC. FOR THE WORKING MODEL: $W \to 0$ AND $\beta \simeq \phi/20$

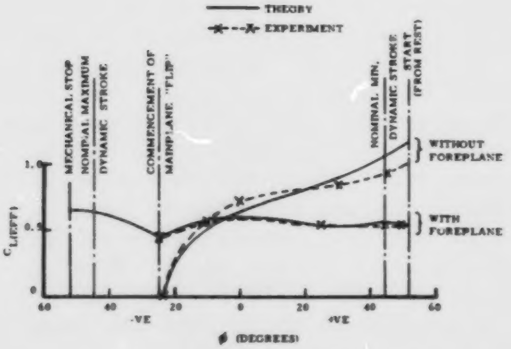


FIG. 9 SYSTEM EFFECTIVE LIFT COEFFICIENT, BASED ON MAINPLANE AREA, VERSUS BEAM ANGLE ϕ

oscillating beam unit obtained from static operation of the machine in a relatively large open-jet wind-tunnel in which the model constituted a negligible blockage. Figure 9 serves to show the constancy of $C_{L(EFF)}$, and hence the unlikelihood of stalling, provided the wind speed exceeds the cut-in value, when both the canard and the mainplane are in use. The same open-jet wind-tunnel was used to establish the characteristics of the model oscillating beam system under normal operating conditions.

PUMPING PERFORMANCE OF MODEL

The pump equipped wind-tunnel model, Fig. 1 and 2, was tested in the open-jet wind-tunnel referred to previously. These tests were aimed at establishing the dynamic performance of the system under both pumping (i.e. loaded) and unloaded conditions, i.e. with the pump disconnected. Only the result obtained using the load pump are reported here; the results for unloaded operation can be found elsewhere (3).

The results obtained with the glandless, leather-sealed plunger, pump in operation are presented in Fig. 10. The pump is of 26.3 mm (1.035 in) bore; the lift was 381 mm (15 in). The machine was adjusted to be tail-heavy in the manner described previously. The cut-in wind speed was approximately 3.4 m/s (11 ft/s or 7.5 mile/h). It should be noted that the tests were conducted in Calgary which, due to altitude, has an ambient pressure typically 12.8% lower than that at sea level; no corrections to compensate for this situation were applied to the results presented in Fig. 10.

A concern with the oscillating beam configuration is its yawing capability. This concern centers on two areas, namely the use of a simple wooden yaw bearing and also placing reliance on the net yaw-tracking moment due primarily to the lift and drag

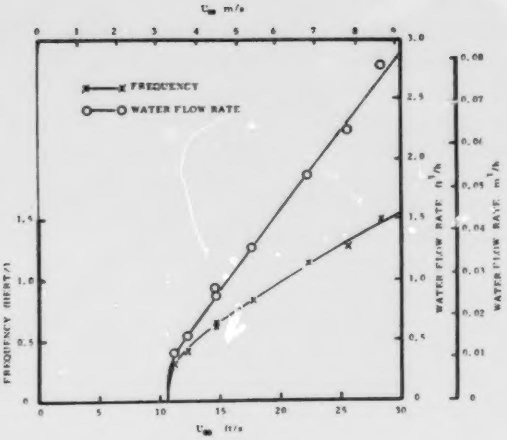


FIG. 10 PERFORMANCE OF WORKING MODEL IN WIND-TUNNEL

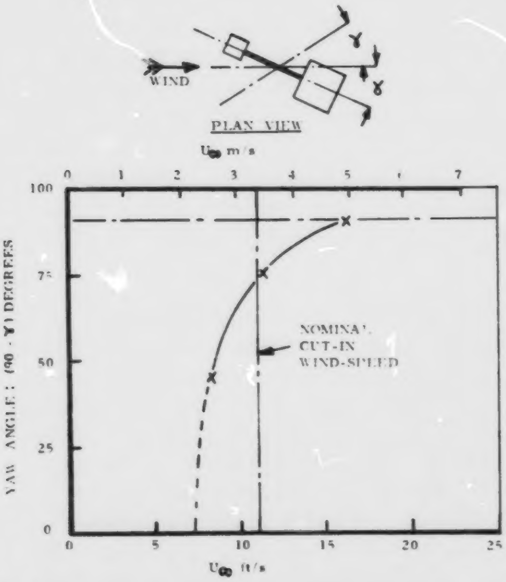


FIG. 11 WIND-TRACKING BEHAVIOR OF MODEL

forces acting on the lifting surfaces plus the doubtless small contribution from the twin mainplane fin-like chordwise ribs. Figure 11 shows the yaw characteristics of the system; it can be seen that at the cut-in wind speed the machine is typically yawed at ±15° or so to the true direction of the wind, a situation which was viewed as acceptable. A point to note, however, is that the machine will only track correctly when the initial yaw malalignment angle at the time a wind restarts is less than about ±90°. Again, this is not viewed as a serious restriction. However the yaw performance of the model indicates that there may be yaw problems with a full-scale unit.

FULL-SCALE PROTOTYPE

A full-scale prototype was built which was very similar to the working model illustrated in Fig. 1 and 2 but which was twelve times larger. This resulted in a mainplane chord D (see Fig. 4) of 2.439 m (8 ft). The machine is shown, in operation, in Fig. 12 and 13. Figure 12 shows the mainplane ascending whilst Fig. 13 was taken as the mainplane descended. Most of the tower, the oscillating beam and most of the bearing blocks were made from (nominally) 102 mm x 102 mm (4 in x 4 in) studding timber as used for house framing, etc. The lower portions of the tower, like that of the wind-tunnel model, was provided with diagonal bracing rods. The tower was stabilised by a screw-in type anchor at each corner. The piece of timber projecting upwind from halfway up the tower was to assist in providing access to the counterweight attached to the upwind end of the oscillating beam. The airfoil surfaces were made from corrugated galvanised steel sheet. As was the case for the model, a glandless, leather-sealed plunger, lift pump was mounted vertically in the tower. The pump cylinder was ABS pipe of 102 mm (4 in) bore. This diameter was, when account was taken of the lift of 3.05 m (10 ft), approximately 10% smaller, and hence 21% less in cross-sectional area, than the pump bore indicated as appropriate by scaling from the wind-tunnel model.

The pumping performance of the full-scale prototype is presented in Fig. 14. Again no correction was made to take into account the low ambient pressure resulting from the elevated test site. The site wind speed, measured at

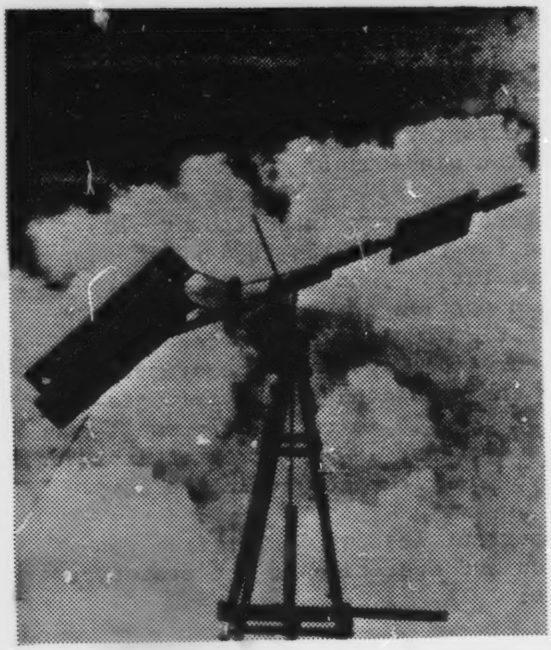


FIG. 12 FULL-SCALE UNIT: MAINPLANE ASCENDING

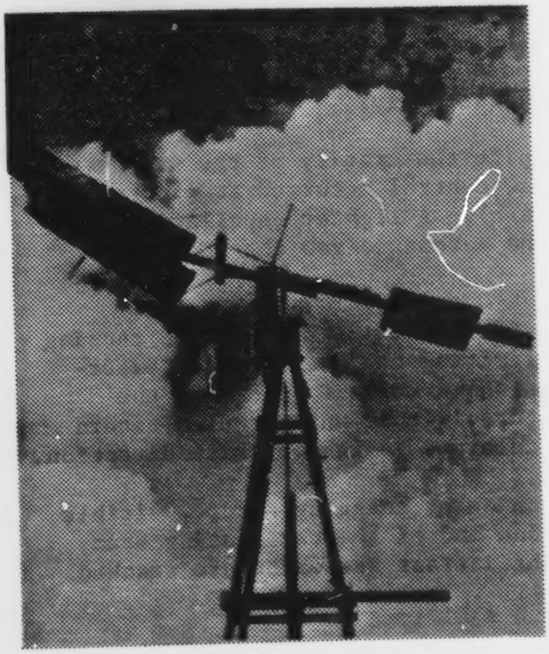


FIG. 13 FULL-SCALE UNIT: MAINPLANE DESCENDING

the oscillating beam pivot height, was obtained from a cup type R.M. Young anemometer mounted a little to one side and upwind of the oscillating beam pumper. The predicted performance curve, shown dotted in Fig. 14, was based on the corresponding wind-tunnel model water-flowrate curve of Fig. 10. The transformation from the model to full scale conditions was based on the application of Newton's Second Law and the premise that were S is the scale factor between the model and full scale:

$$\text{Linear dimensions} \propto S \quad (1)$$

$$\text{Aerodynamic forces} \propto S^2 \quad (2)$$

$$\text{(for a prescribed } U_\infty\text{)}$$

$$\text{Component masses} \propto S^3 \quad (3)$$

when the full scale unit is an exact scale-up of the model. This leads to the conclusion that for a prototype exactly scaled, in every respect, from the model that for a prescribed wind speed U_∞:

$$\text{Operational frequency} \propto 1/S \quad (4)$$

In practice the component masses, particularly the very dominant mass of the mainplane, may not scale up exactly in proportion to S^3. This situation can arise, very easily, due to the selection of a method of construction, and a choice of materials, differing from those of the model. For such cases it can be shown that where:

$$M \equiv \text{Mass per unit area/(Mass per unit area of model) } S^3$$

a modified form of equation (4) is applicable namely:

$$\text{Operational frequency} \propto 1/S\sqrt{M} \quad (5)$$

Normally, since the polar moment of the oscillating beam, mainplane and canard system is totally dominated by the mass of the mainplane it appears to be adequate to base M on the mainplane mass only.

A corollary of the dynamic analysis of an unloaded oscillating beam pumper is that for a prescribed machine the:

$$\text{Operational frequency} \propto U_\infty \text{ (Constant)} \quad (6)$$

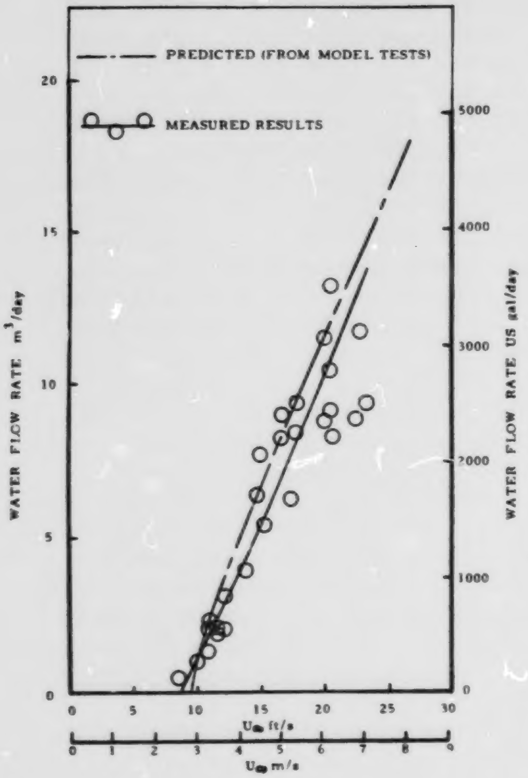


FIG. 14 PUMPING PERFORMANCE OF FULL-SCALE PROTOTYPE (3.05 m (10 ft) LIFT)

Wind tunnel tests of unloaded oscillating beam units (1,3) have confirmed the validity of equation (6).

The scale factor S of the prototype relative to the wind-tunnel model was 12 and the appropriate mass ratio, M, = 1.88. Taking these factors into account plus allowing for the smaller-than-scale pump of the prototype lead to the transformation of a portion of the water-flow-rate curve of Fig. 10 into the corresponding dotted curve of Fig. 14. The discrepancy between the predicted and experimental curves of Fig. 14 is relatively small and tends to decrease as U_∞ increases implying, possibly, some leakage within the pump.

Important lessons learnt from construction and operation of the prototype unit are:

i) a damper was found to be essential to reduce the severity of the "flip over" of the mainplane at the end of each stroke. A simple, low pressure, air cylinder damper employing a leather sealed piston was developed for this purpose and has been found to work satisfactorily,

ii) despite the crudity of the yaw bearing design it was found that automatic yaw control occurred at wind speeds above about 4.5 m/s (14.8 ft/s or 10 mile/h). A lighter oscillating beam system should also tend to reduce the automatic-yaw threshold wind speed,

iii) it was found that wind gusting had the effect, once in a while, of causing the beam to impact the mechanical stops limiting the beam angular excursion. It would appear that elastic stops would serve to minimise the impact moment applied to the tower structure in this way and also return energy to the beam to assist it to re-accelerate in the opposite direction.

iv) it proved relatively easy to stop the machine by snagging a rope, visible in Fig. 12 and 13 attached to the mainplane end of the oscillating beam, on a convenient tower ground anchor at the instant the mainplane reached its lowest position.

Materials for the prototype unit, including ready-made items such as turnbuckles, were all purchased at retail rates at a total cost of just under $900 (in Canadian funds). The fabrication time came to a total of 105 man hours; additional time was required for site erection, etc. No jigs, fixtures or other aids were available for expediting manufacture. Furthermore the water pump plunger was machined from the solid for the prototype whereas a simple, unmachined, brass casting could probably be used if the machine were produced on a quantity basis.

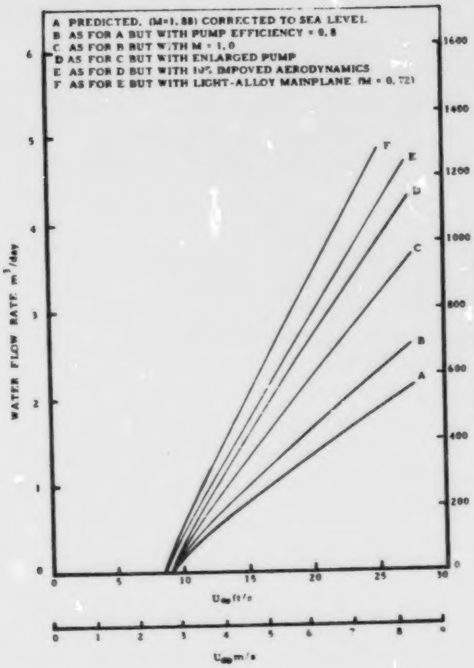


FIG. 15 PROJECTED PUMPING PERFORMANCES OF VARIOUS DEVELOPMENTAL VERSIONS OF THE FULL-SCALE PROTOTYPE

DEVELOPMENT POTENTIAL

Questions that can be asked are; what is the development potential of the twin airfoil, canard type, oscillating beam water pumper? Also; how does the performance of an oscillating beam machine compare with that of a conventional rotary type wind-driven water pumper? Figure 15 was produced to indicate, at least partially, the performance potential of oscillating beam pumpers of the size of the prototype unit. Curve A of Fig. 15 is reproduced from the dotted curve of Fig. 14 with addition of a correction to transform the predicted performance for Calgary to that which can be expected at sea level and also for a 30.5 m (100 ft) lift instead of one tenth of this magnitude as is applicable to Fig. 14. Curve B is a better indication of what should be possible if an expected increase of water pump efficiency from 0.65 to 0.80 occurs due to the tenfold increase of lift which reduces the relative significance of pump-valve flow losses and the inherent pump-piston friction losses. Curve C of Fig. 15 shows the additional benefit to be obtained by reducing M from 1.88 to unity, a value which corresponds to a full-scale mainplane mass of approximately 8.8 kg/m^2 (1.8 lbm/ft^2). Curve D represents the predicted performance if, with $M = 1.0$, an enlarged pump of 10% increased bore is fitted. The curve E represents the performance to be expected if it should prove possible to achieve a 10% better aerodynamic performance than is implied from model tests. At least a small improvement should result simply due to the Reynolds number of the prototype being greater than that of the model. The last curve, curve F, shows the additional benefit to be obtained by employing corrugated aluminum sheeting etc. for the mainplane; this modification results in an expected value of; $M = 0.72$.

It can be seen, from Fig. 15, that there is approximately a 2:1 range of water flow rate between performance curves A and E. It would appear that with some structural modifications plus a correctly sized pump it should be possible, still retaining corrugated steel sheet as the airfoil material, to obtain a performance close to that implied by curve C. The writers are not greatly attracted to the idea of a cloth-covered light frame type mainplane as a means of lightening the latter component since the cloth is subjected to cyclic load reversals, a situation which may well cause the cloth covering to stretch. In some countries cloth is also a premium substance which is another disadvantage. Another possibility is to replace the rectangular airfoils with delta-wing shapes in order to obtain superior aerodynamic performance.

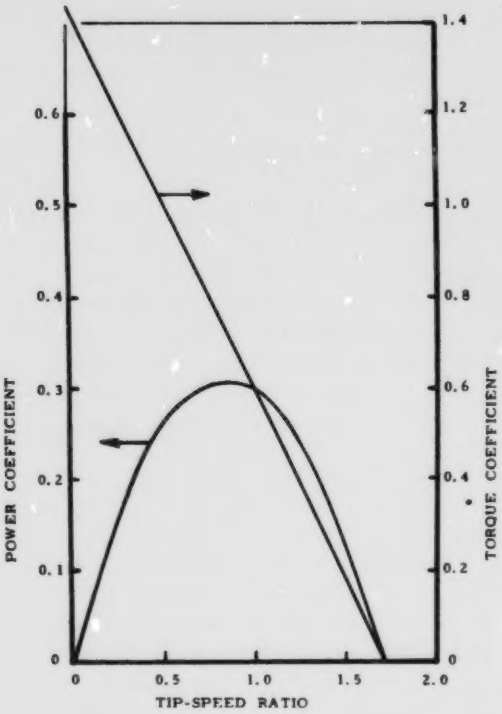


FIG. 16 PERFORMANCE CHARACTERISTICS OF A TYPICAL, SMALL, MULTIBLADED WIND-TURBINE ROTOR

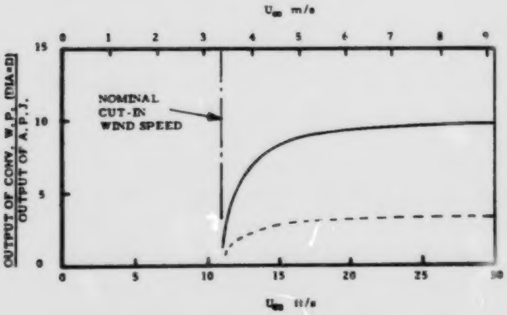


FIG. 17 COMPARISON OF THE PERFORMANCES OF OSCILLATING BEAM, OR AEOLIAN PUMPJACK (A.P.J.), WITH CONVENTIONAL ROTARY WATER PUMPING TURBINE OF DIAMETER D (MECHANICAL EFFICIENCY = 0.9, PUMP EFFICIENCY = 0.7)

A disadvantage of this is that structural complexity is increased. The use of corrugated aluminum sheet material for the airfoil surfaces is perfectly acceptable provided such material is readily available and also provided local climatic conditions do not lead to major corrosion problems.

In order to assess the performance of the oscillating beam pump relative to more conventional systems, a performance comparison was carried out with that of a conventional multibladed wind-turbine mechanically coupled to a fixed-stroke reciprocating water-pump. The turbine was of diameter D, i.e. 2.44 m (8 ft) a dimension equal to the mainplane chord of the oscillating beam machine. The power and torque coefficients of the rotary multibladed turbine are presented in Fig. 16. Figure 16 is essentially a composite of a number of previously published performance characteristics of typical multibladed machines (4). The two curves on Fig. 17, a comparison of the pumping performances of the multibladed and oscillating beam, or aeolian pumpjack (A.P.J.), machines, reflect the two extremes of comparison. The solid curve of Fig. 17 is based on the assumption that for the rotary unit the pump is connected to the turbine in such a way that the torque produced by the turbine to drive the pump is uniform. The dotted curve reflects the more usual situation where the pump load is not balanced in any way and hence the relatively high peak starting torque required governs, for a prescribed cut-in wind speed, the size of pump used.

The oscillating beam-pump performance curve upon which the comparison was based is curve E of Fig. 15. Hence on the basis of curve E of Fig. 15 and the dotted curve of Fig. 17, the conventional rotary machine has a performance approximately three times better than that of the APJ or, if the comparison is made for the extreme, hypothetical, situation represented by the solid curve of Fig. 17 the performance of the rotary unit is, potentially at least, ten times that of the APJ. When the comparison is between what is essentially the demonstrated performance capability of the APJ, curve A of Fig. 15, with the lower performance of the rotary unit the water flow rate of the rotary unit is approximately six times that of the APJ.

Whilst this performance comparison is, at first glance disappointing, it is due primarily to the low "tip-speed" ratio and hence low frequency of the oscillator, it should be borne in mind that a 2.44 m (8 ft) diameter multi-bladed machine would require a reduction gear if coupled to a deep-well pump and also requires a means, for example a crankshaft and connecting-rod, for converting rotary motion into reciprocating motion. The rotary machine is, therefore, a much more sophisticated device less well suited to owner maintenance than the low frequency oscillating beam system with simple wooden-block type bearings.

It would appear that, when well drilling costs are taken into account, an oscillating beam pump may represent the most cost effective solution when wells of relatively moderate depth, say up to about 30.5 m (100 ft) or at the most 61 m (200 ft), are required provided moderate water flow rates are acceptable such as might be the case for small, single family, farms, etc. For cases where the water table is very low, and hence where well drilling costs are relatively high, conventional rotary wind driven water-pumpers are likely to prove more cost effective on an overall basis.

CONCLUSIONS

A description has been given of a very simple, easy to manufacture and maintain, twin airfoil, canard type oscillating beam wind-driven water pumper. The concept has been demonstrated in the form of both a fully functional wind-tunnel model and also as a full-scale prototype unit. The system was shown to function satisfactorily, although not very efficiently when compared with the performance of conventional wind-driven water-pumpers. It was also shown that there appears to be potential for improving substantially the performance of the full-scale prototype. It appears that an improved full-scale machine may have a performance adequate for small farms when the required lift is less than about 30.5 m (100 ft). The machine should prove maintainable, at the farm or village level, indefinitely without the need for speciality spare parts and components.

REFERENCES

1. Kentfield, J.A.C., A Simple Aeolian Pumpjack for Indigenous Construction in Developing Nations. Proceedings, 1985 AWEA Conference.

2. Zin, C.R., Kansans' Wind Pump Stirs Interest. Feature article, Topeka Capital Journal, Feb. 23, 1986.

3. Kentfield, J.A.C., The Performance of a Simple, Oscillating Beam Type, Wind-Driven Water Pumper. Proceedings, 1986 AWEA Conference.

4. Kentfield, J.A.C., A Performance Comparison of Various Wind-Turbine Types for Powering Water Pumps. Proceedings, 17th Intersociety Energy Conversion Engineering Conference, Los Angeles, August 1982.

PERFORMANCE TESTING OF THE DELTX WP-20

D. Baker[1] and B. A. Paterson[2]

SUMMARY

In 1985, a proposal was submitted to the National Research Council requesting funds to evaluate the Deltx WP-20 wind pump at the Lethbridge Wind Research Site. The WP-20 is manufactured in Calgary by the Deltx Windpump Corporation for use in the irrigation, drainage and municipal water supply areas. Interest in purchasing the unit has been high but potential buyers are waiting until full testing of the machine's performance is carried out.

The results of the performance testing were mixed. Pumping performance of the machine exceeded expectations by a wide margin but this was offset by numerous mechanical problems. Due to these problems, data gathering operations at the test site were unable to obtain a complete performance curve of this unit. Both optimistic and pessimistic extrapolations of the curve indicated that the performance of the WP-20 relative to its swept area was much better than any water pumper tested on the site to date. In Lethbridge it was estimated that it would pump between 131 000 and 180 000 m^3/a (at six metres lift). With a swept area of 19.6 m^2, this translates to between 6 700 and 9 200 m^3 per square metre of swept area. Its nearest competitor, the Wind Baron, was calculated to have the potential of pumping 4 500 m^3 per square metre of swept area. It is expected that with relatively minor improvements and simplification of the pump linkage apparatus, the WP-20 would prove to be highly competitive in the wind pump market.

INTRODUCTION

In 1982 the Drainage Branch of Alberta Agriculture, in conjunction with Jensen Engineering and the Alberta Research Council, established a wind turbine test site near Lethbridge in order to evaluate and demonstrate the use of wind turbines for pumping water in Alberta. Funding was provided by Farming for the Future, the Alberta/Canada Energy Resources Research Fund, Alberta Agriculture and TransAlta Utilities.

Since the formation of this test site, a local Calgary company (Deltx) designed and manufactured a Delta-blade wind pump. The company demonstrated this machine for a short period of time during the summer of 1984. In 1985 a proposal was submitted to the National Research Council for funds to test the Deltx WP-20 wind pump at the Lethbridge Wind Test Site. This unit is a smaller prototype (rotor diameter of 5 m) of the original Deltx wind pump (rotor diameter of 15.9 m). Funds for the testing were approved and the WP-20 was transported from Calgary and installed at the Lethbridge Wind Research Site in December, 1985. This report presents the results of the testing program and discusses the performance of the Deltx WP-20.

---

[1] DRB Engineering Consultants Ltd., 116 Hawkwood Way N.W. Calgary, Alberta
[2] Alberta Agriculture, Agriculture Centre, Lethbridge, Alberta T1J 4C7

DELTX WP-20 SPECIFICATIONS

The WP-20 was designed and manufactured entirely by the Deltx Windpump Corporation of Calgary, Alberta. The unit is an upwind, horizontal axis wind turbine with eight steel delta shaped blades and a rotor diameter of 5 m (Figure 1).

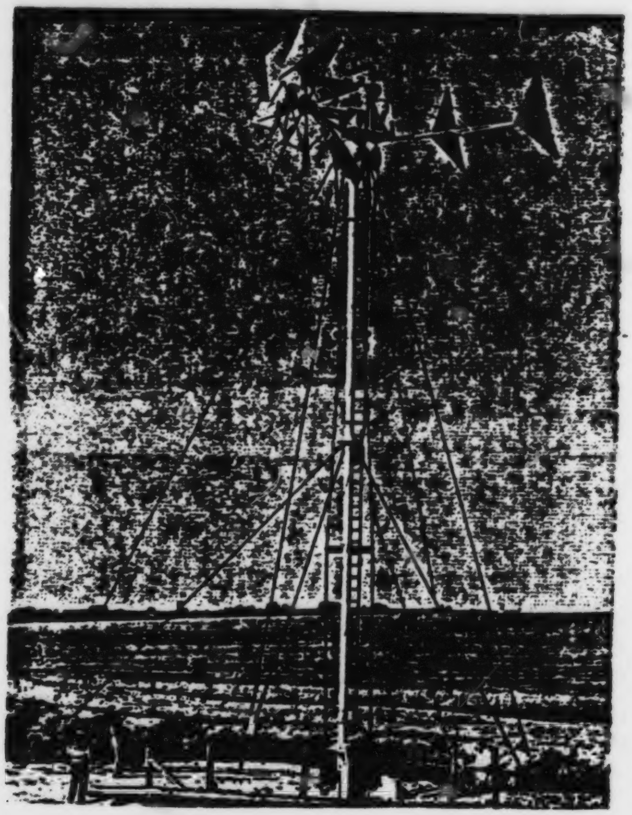


Figure 1

The turbine is mounted on a 15.2 m single pipe tower and guyed with four steel cables mounted to four steel screw anchors (modified from above figure). The pump system consists of dual positive displacement, reciprocating piston pumps, each 0.59 m in diameter. The pump stroke was fixed at 7.6 cm. The projected cut-in wind speed was 17.5 km/h and the furling wind speed was set at 35 km/h, with the turbine completely stopping at 56 km/h. The design survival wind speed for this unit is 190 km/h.

TEST PROCEDURE

To accommodate the WP-20's dual reciprocating pumps, a larger test circuit than was available at the test site was required. A test circuit was designed by the test site management team (Figure 2). Due to time constraints this test circuit was not built; instead a circuit designed and built by Deltx was brought down with the machine. This test circuit consisted of a single vertical pipe extending from the pumps up to the predetermined test head, at which point it made a 180° turn and returned to the sump. A vent was installed at the top of the test circuit to eliminate syphoning effects. An in-line turbine type meter was installed on the vertical rise to measure the output of the pumps. This had the disadvantage of not providing any dampening of the pulsating flow before entering the flow meter nor did it allow for any filtering of foreign matter before water was pumped through the flow meter.

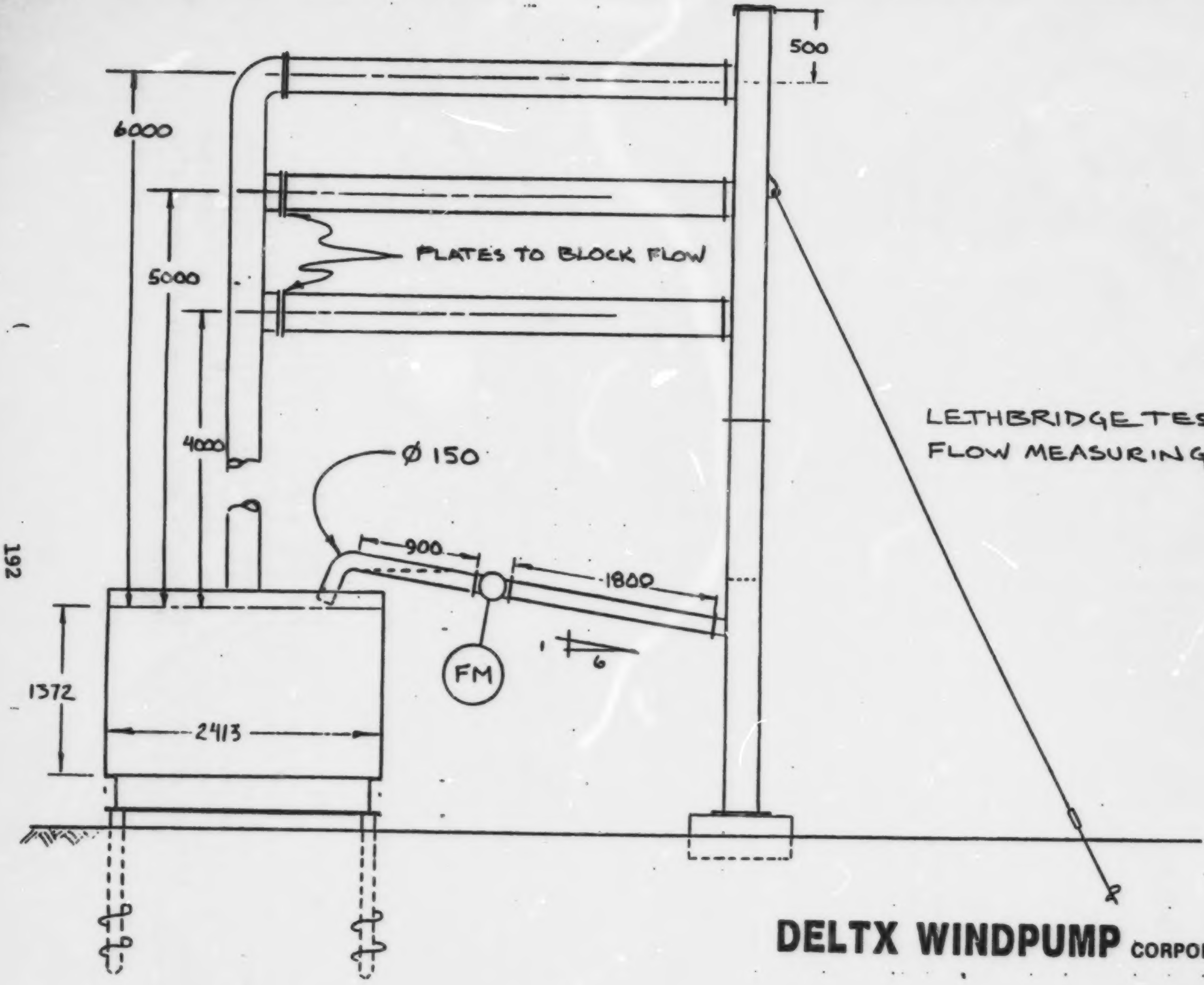
The WP-20 was the first machine tested under winter conditions at the Lethbridge Wind Research Site. This required that the fluid to be pumped be freeze protected and yet maintain as much of the characteristics of water (the fluid which would normally be pumped) as possible. This was achieved by adding calcium chloride to the water. This solution of 20% calcium chloride resulted in an increase of the density (and hence the effective pumping head) by approximately 10% and provided freeze protection to -18° C.

The flow meter was connected to the data acquisition system on January 13, 1986. Data from this meter and the nearby wind speed sensors were collected and stored as ten minute averages on the data acquisition's ten megabyte hard disk. Daily summaries were produced and the data was transferred to an IBM PC on a weekly basis for analysis purposes.

RESULTS

After the first week of operation at the test site (prior to the flow meter being connected), the pivot pins for the pump arms sheared off (approximately December 30, 1985) and the wind pump was shut down. The wind pump was not recommissioned until January, 1986, the date the pins were replaced. Data was collected from January 30 to February 6, 1986 at which time the turbine meter appeared to be clogged with foreign material. Before the meter could be cleaned, the WP-20 failed again. This time, a different connecting pin as well as a connecting rod bearing failed. Extreme weather conditions prevented the repair of this unit before the end of the test period (February 25, 1986).

The performance curve shown in Figure 3 (and Table 1) is based on the data collected during the six operational days of the system. It shows a cut-in wind speed of 15 km/h, which is much higher than normal for most competitive wind pumpers. The flow rate increases dramatically from 20 km/h to 27 km/h and becomes a constant 21 l/s from 30 to 36 km/h. The small amount of data collected above 30 km/h indicated that the unit had initiated furling. Although predicted by the manufacturer, furling at 30 km/h is also an unusually low speed for most wind pumpers.


500
6000
5000
4000
PLATES TO BLOCK FLOW
Ø 150
900
1800
1
6
FM
1372
2413

LETHBRIDGE TEST CENTER
FLOW MEASURING SYSTEM

DELTX WINDPUMP CORPORATION

SUITE 204, 2750 - 22nd STREET N.E.
CALGARY, ALBERTA, CANADA
T2E 7L9

Figure 2

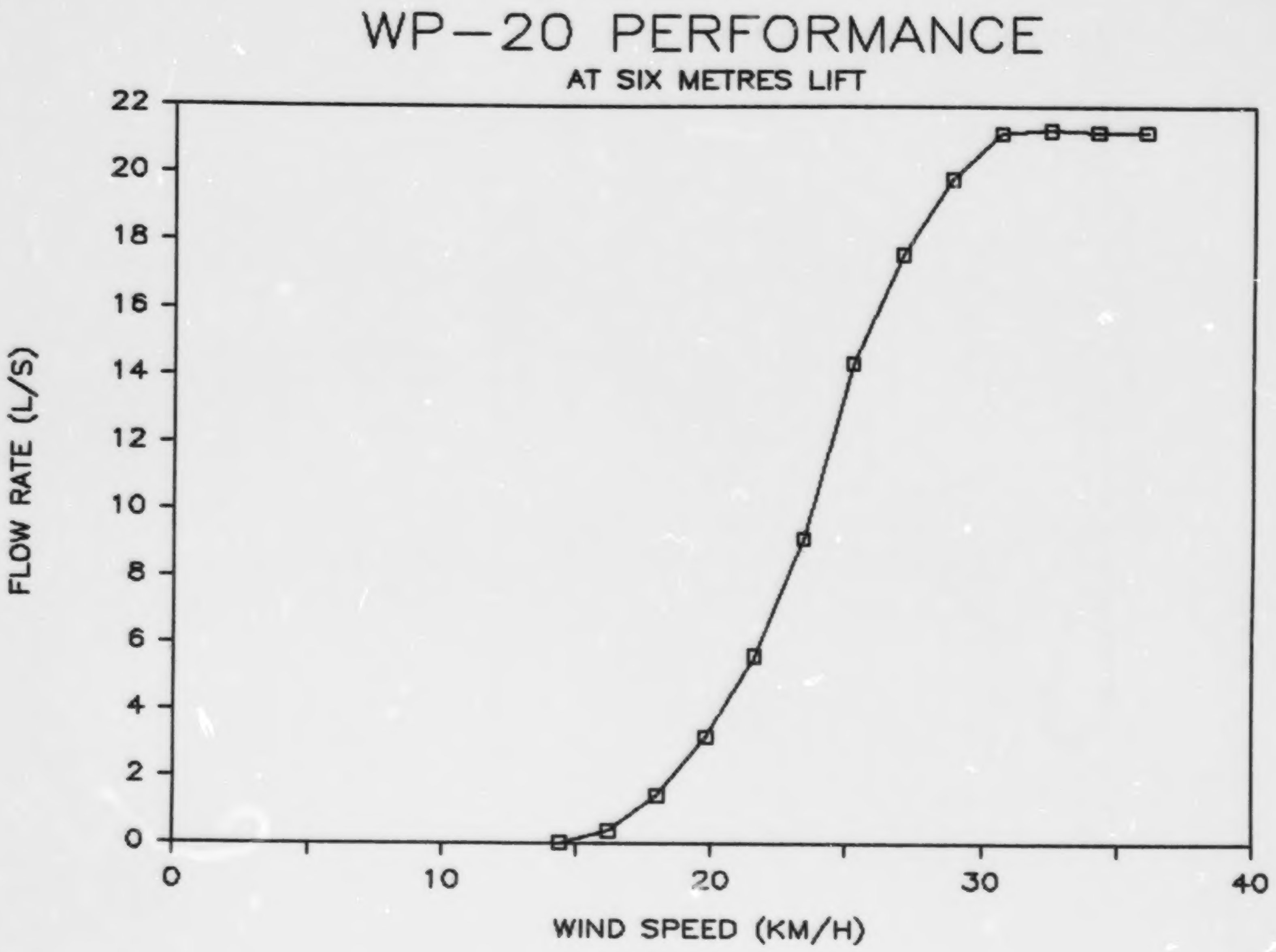

WP—20 PERFORMANCE
AT SIX METRES LIFT
FLOW RATE (L/S)
22
20
18
16
14
12
10
8
6
4
2
0
0
10
20
30
40
WIND SPEED (KM/H)

Figure 3

Table 1. WP-20 Performance At Six Metre* Lift

WIND SPEED (km/h @ hub height)	PUMPING RATE (l/s)
15.3	0.00
16.2	0.36
18.0	1.39
19.8	3.15
21.6	5.50
23.4	9.00
25.2	14.10
27.0	17.40
28.8	19.60
30.6	21.00
32.4	21.10
34.2	21.00
36.0	21.00

* Effective head after accounting for increased density of Calcium Chloride Solution

The performance curve in Figure 4 is compared with a Wind Baron Mark III windmill. Optimistic and pessimistic extrapolations of the WP-20's performance above 36 km/h have been added to the graph and will be discussed later in this report. The Mark III Wind Baron is the previously most efficient wind pumper tested at the site. It has eighteen blades and a 6.4 m diameter rotor. Its performance curve displays a much lower cut-in wind speed and a higher furling wind speed. The Wind Baron has 62% more swept area than the 5 m diameter WP-20, yet its maximum pumping rate is 30% less than the WP-20. This may be due to the different pump sizes (for the Wind Baron to pump the same volume, the rotor would have to turn 4.6 times faster than the WP-20). It is also possible that the theoretical increase in efficiency of the Delta-blade rotor contributes to the WP-20's pumping performance. Likewise, the Wind Baron's high gear ratio and low volume pump allows it to cut-in at much lower wind speeds (to the detriment of its operating efficiency at higher wind speeds). A comparison of these two units is shown in Table 2. The relatively high cut-in wind speed of the WP-20 is believed to be the result of the large mass of the system (the unit was originally designed to operate in winds up to 80 km/h) and the complex pump linkages. The pump linkage was designed for a variable stroke controller; the manufacturer has indicated that the linkage will be simplified for future fixed stroke machines. This should lower the cut-in wind speed of the machine as well as eliminate many of the mechanical failures which occurred on the test unit. Because of the lack of performance data above 36 km/h, it is not known if the machine possesses any serious performance deficiencies due to its initiation of furling at the low wind speed of 30 km/h.

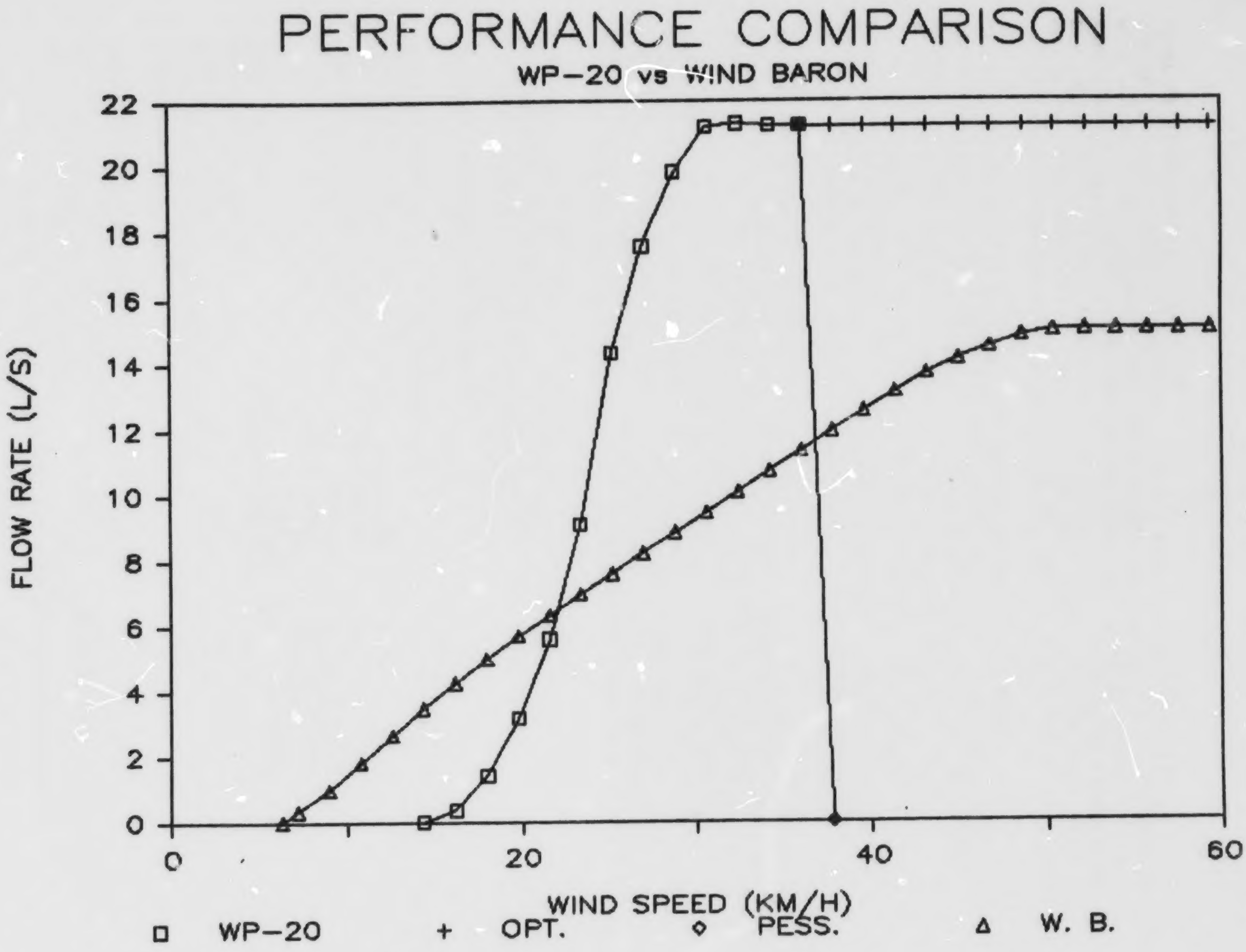

PERFORMANCE COMPARISON
WP-20 vs WIND BARON
FLOW RATE (L/S)
0
2
4
6
8
10
12
14
16
18
20
22
WIND SPEED (KM/H)
0
20
40
60
□ WP-20
+ OPT.
◇ PESS.
△ W. B.

Figure 4

Table 2. Comparison of the WP-20 and Wind Baron Water Pumpers

	WP-20	Wind Baron
Physical Characteristics:		
Rotor Diameter (metres):	5	6.4
Swept Area (square metres):	19.6	32.2
Number of Blades:	8	18
Hub Height (metres):	15.2	12.2
Pump Type:	Counter-balanced Dual Positive Displacement Reciprocating	Counter-balanced Positive Displacement Reciprocating
Pump Size (stroke X dia):	7.6 cm X 59 cm	30 cm x 43 cm
Gear Ratio:	1:2 (Dual Pumps)	3.25:1
Volume per Pump Cycle (litres):	44 (2 X 22)	31 (1 X 31)
Measured Performance Highlights:		
Cut-in Wind Speed (km/h):	15.3	6.3
Furling Wind Speed (km/h):	30.0	50.7
Maximum Pumping Rate (l/s):	21.1	14.8

To accurately assess and compare the performance of wind pump machines, estimates of the expected annual pumping volumes in various wind regimes are required. For this report, the WP-20's performance was applied to three sites in Alberta where the wind regime has been analyzed by the Atmospheric Environment Service and characterized by Weibull parameters. The results are shown in Figure's 5 and 6. The pumping yields in Figure 5 were calculated from the optimistic projection of the WP-20 performance curve in Figure 4. Likewise, the pumping yields in Figure 6 were calculated from the pessimistic projection of the WP-20 curve.

In past analyses, machines with lower cut-in wind speeds would pump larger volumes on an annual basis than machines with slightly higher maximums. For Fort McMurray, where the mean wind speed is only 9 km/h, Figure 7 shows that regardless of the WP-20's performance above 36 km/h, the Wind Baron is able to pump close to twice the amount that the WP-20 pumps. However, in Lethbridge (Figure 8, average wind speed of 18 km/h) the WP-20 pumps significantly more than the Wind Baron using the optimistic projection, and only slightly less when the pessimistic projection is used.

To properly compare these pumping yields, they should first be normalized on the basis of swept area. Table 3 shows that while the Wind Baron had previously been the most efficient wind pumper tested, the WP-20 exceeds the Wind Baron's efficiency in Lethbridge and Edmonton. Only in the very poor wind regime of Fort McMurray does the Wind Baron's efficiency exceed that of the WP-20. For comparison purposes, Table 3 also includes the data from all other machines tested at the site.

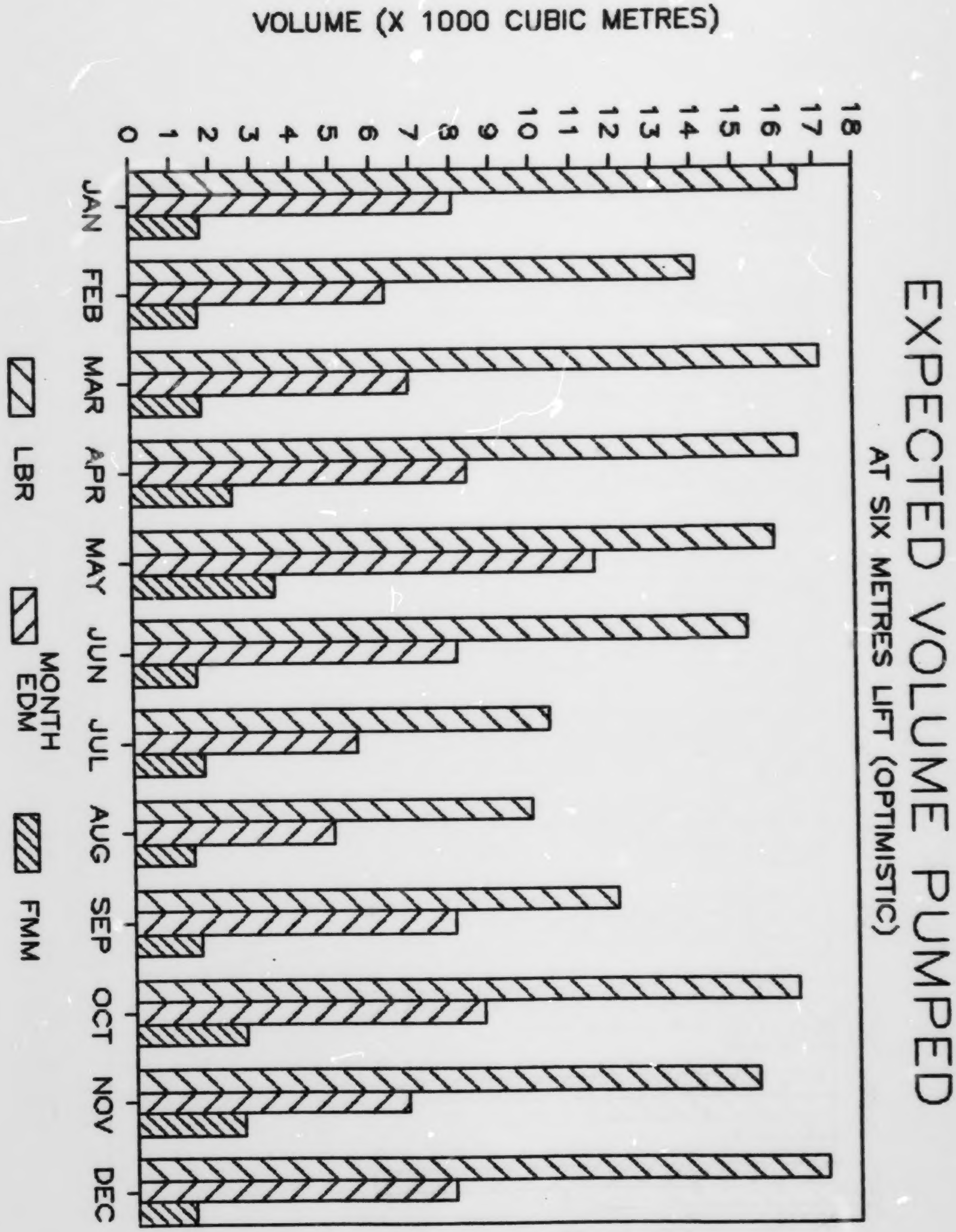

EXPECTED VOLUME PUMPED
AT SIX METRES LIFT (OPTIMISTIC)
VOLUME (X 1000 CUBIC METRES)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH
LBR
EDM
FMM

Figure 5

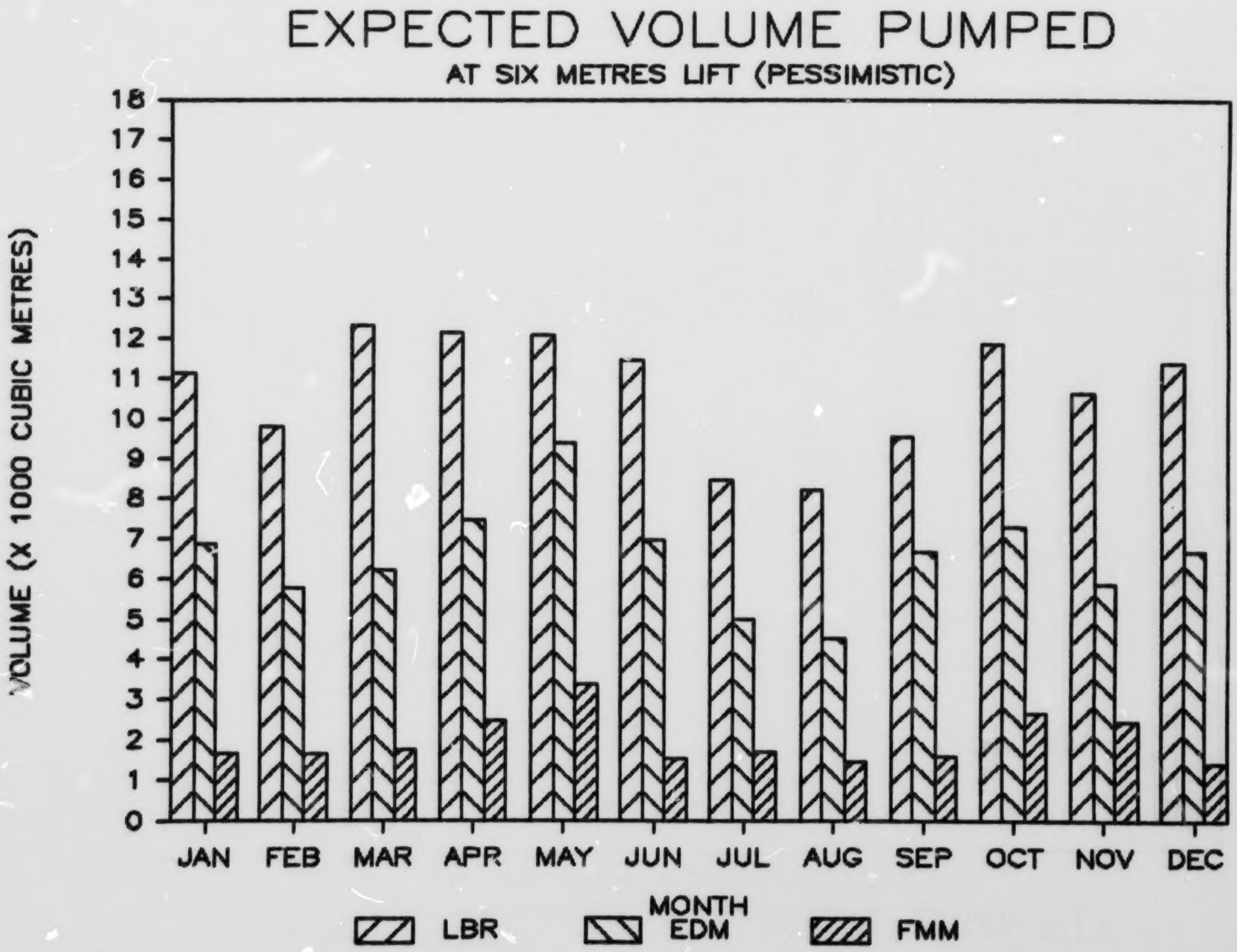

EXPECTED VOLUME PUMPED
AT SIX METRES LIFT (PESSIMISTIC)
VOLUME (X 1000 CUBIC METRES)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH
LBR
EDM
FMM

Figure 6

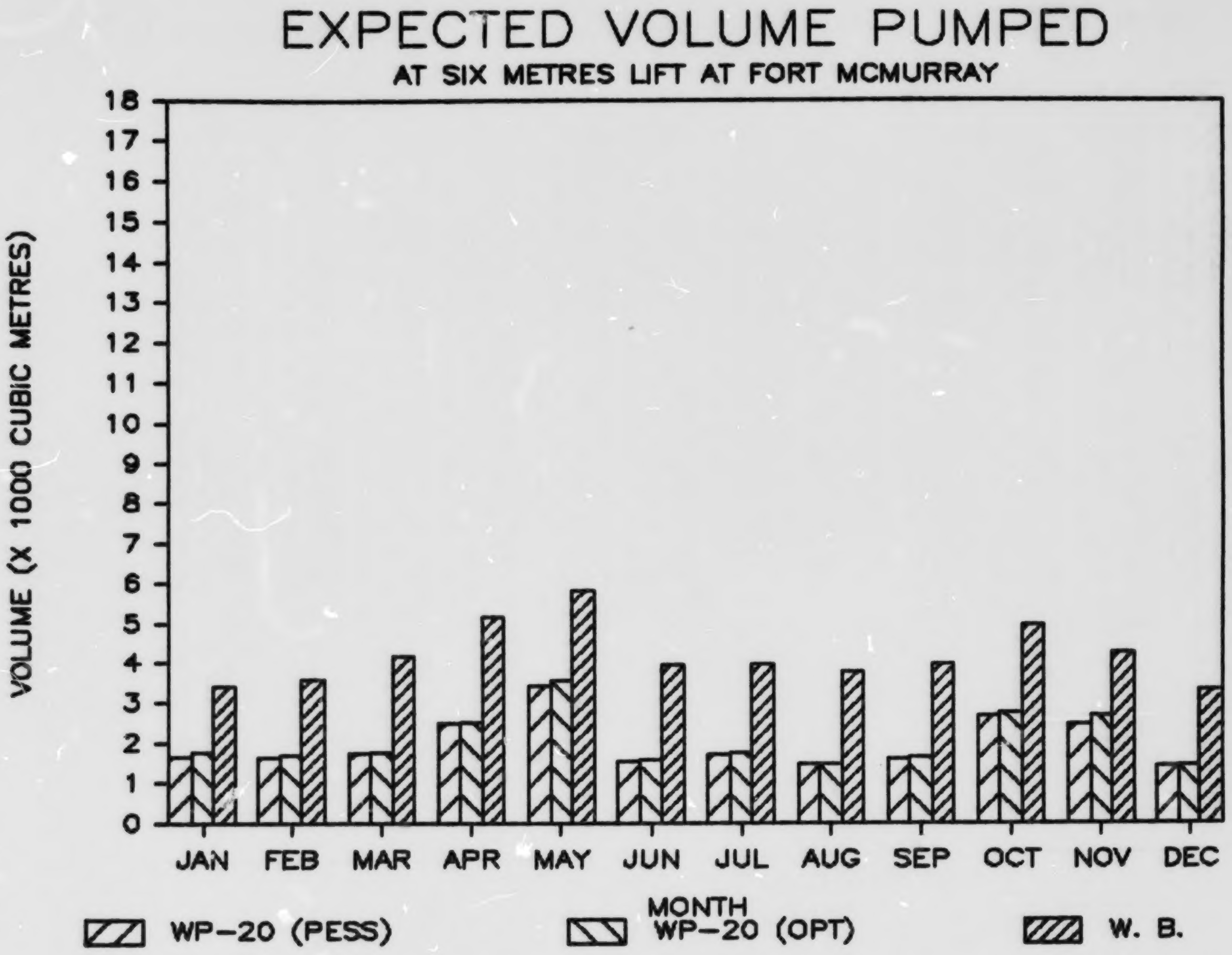

EXPECTED VOLUME PUMPED
AT SIX METRES LIFT AT FORT MCMURRAY
VOLUME (X 1000 CUBIC METRES)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH
WP-20 (PESS)
WP-20 (OPT)
W. B.

Figure 7

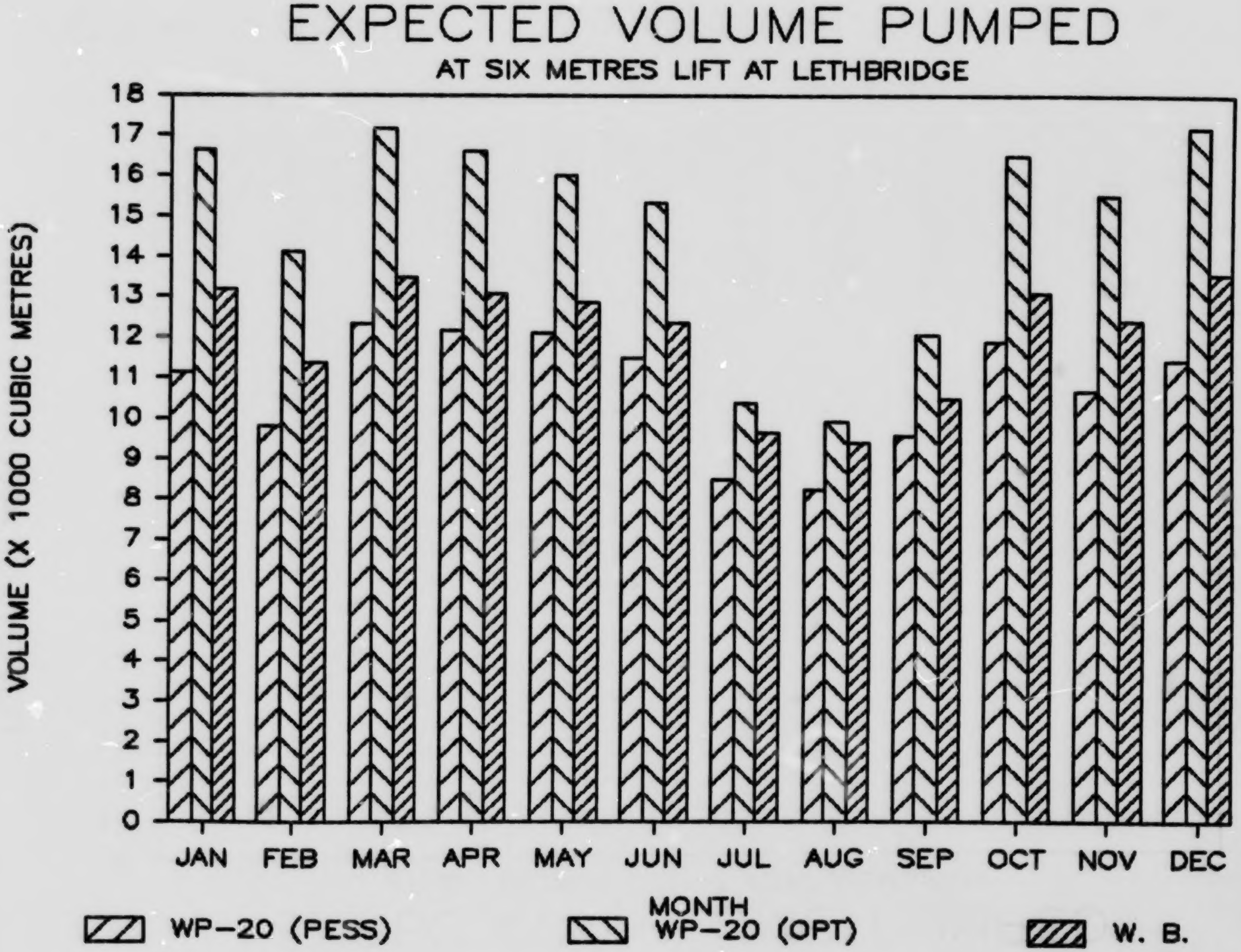

EXPECTED VOLUME PUMPED
AT SIX METRES LIFT AT LETHBRIDGE
VOLUME (X 1000 CUBIC METRES)
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
MONTH
WP–20 (PESS)
WP–20 (OPT)
W. B.

Figure 8

Table 3. Annual Volume/Swept Area Comparison
(X 1000 Cubic Metres/[Square Metre])

	Lethbridge	Edmonton	Ft. McMurray
WP-20 (Opt.)	9.17	4.73	1.31
WP-20 (Pess.)	6.67	4.09	1.27
WIND BARON	4.51	2.98	1.56
BOWJON	2.69	1.92	0.95
WILKES CAM	1.84	1.43	0.86
GRAHAM	3.37	1.02	0.13
WINCHARGER	1.60	0.89	0.25
MAVERICK	0.79	0.53	0.17

CONCLUSIONS AND RECOMMENDATIONS

The WP-20 outperformed all units previously tested at the Lethbridge Wind Research Site. The unit's high operating efficiency overcomes its relatively high cut-in wind speed for all but the poorest wind regimes. In the high wind regimes the pumping yield estimates varied by ± 15% due to the lack of performance data above 36 km/h. It is therefore important that further testing of this machine be completed before detailed comparisons or recommendations for its improvement be made.

The WP-20's mechanical integrity requires much improvement. The complicated linkage designed for variable stroke operation cannot withstand the forces present during fixed stroke operation. It is believed the complexity of this linkage, as well as the large mass of the machine, results in an unusually high cut-in wind speed. Provided that the mechanical problems are overcome, this machine should be highly competitive in today's wind pump marketplace.

Discussions with Deltx management indicate that redesign of the pump linkage is underway which should result in; a significant reduction in the weight of the machine, much simpler operation of the pumping system and considerable savings in production cost. Further testing of the redesigned unit is expected to take place at the Lethbridge Wind Test Research Site during the summer of 1986.

POSTER SESSION

FLOW VISUALIZATION FOR AN OSCILLATING PROFILE IN A SIMILAR MOTION WITH THE DARRIEUS TURBINE

Philippe Désy*

Philippe Fraunié**

Claude Béguier**

Ion Paraschivoiu*

ABSTRACT

The purpose of this work is to visualize the flow in the dynamic-stall conditions for an oscillating profile in a water tunnel. The experiment has been performed at IMST Laboratory at Marseilles according to a research work done in collaboration between IMST and Ecole Polytechnique de Montréal.

The oscillating blade is a NACA 0018 profile which has a similar motion to a Darrieus wind turbine blade. In rotation, the angle between the chord and the undisturbed stream flow direction is always the same. That is the way we simulate the kinematic conditions of the Darrieus rotor. The rotating blade has a plunging and pitching motion.

The blade (6.0 cm chord) has a tip-speed ratio between 0.30 and 2.59 with a rotational radius of 6.3 cm. The potential flow is laminar with a speed of 17 cm/s. We can observe the dynamic stall across the plexiglass water tunnel with the utilization of coloured dyes ejected from the leading-edge, the trailing-edge and into the potential flow.

Many pictures taken at about every 5° in the rotational circle show the dynamic-stall phenomenon. We observe the dynamic stall at low tip-speed ratios otherwise vortices intersect the blade and falsify the boundary layer. Some pictures with two flashes show the increase of the boundary layer. A film-script shows all details of the stall phenomenon for different tip-speed ratios.

---

* Department of Mechanical Engineering, Ecole Polytechnique de Montréal

** Institut de Mécanique Statistique de la Turbulence (IMST), Marseille, France

Comparisons with Darrieus motion in similar experimental configuration show that unsteady effects occur in the boundary layer development and in the wake evolution for rotating motions even the reduced frequency K* remains low when interaction effects are significant.

The entrainment effects which differ from one to another motion induce such an unsteady behaviour, especially by a vortex and blade interaction in a specific dynamic-stall kinematic.

NOMENCLATURE

α : local angle-of-attack, deg

α_E : local angle-of-attack for a wind turbine, deg

α_M : local angle of attack for the model, deg

α_O : offset angle, deg

c : blade chord, m

c' : blade chord for a wind turbine, m

C_L : blade airfoil section lift coefficient

C_D : blade airfoil section drag coefficient

C_M : blade airfoil section momentum coefficient

C_P : blade airfoil section pressure coefficient

$k*$: reduced frequency

k_E : reduced frequency for a wind turbine

k_M : reduced frequency for the model

LDV : Laser-Doppler Velocimetry

λ_E : tip-speed ratio for a wind turbine

λ_M : tip-speed ratio for the model

N : number of blades

ω : rotational speed for the experimental model, rad/s

ω' : rotational speed for a wind turbine, rad/s

r : rotational radius for the model, m

R : rotational radius for a wind turbine, m

rpm : revolutions per minute

s : solidity

θ : azimuthal angle, deg

U_∞ : freestream velocity for the model, cm/s

U_{REL} : effective flow velocity on the blade of the model, cm/s

V_∞ : effective upflow velocity for a wind turbine, cm/s

V_{REL} : flow velocity on the blade of a wind turbine, cm/s

1. INTRODUCTION

The dynamic stall is a phenomenon of separation of the boundary-layer on the upper surface of a blade in an unsteady flow [1-5].

We can simulate experimental conditions of the dynamic stall with a experimental model which has a similar motion as the Darrieus wind turbine in an hydrodynamic tunnel. The Darrieus vertical-axis wind turbine has an unsteady complex configuration. During one rotation, the flow velocity relative to the airfoil which consists of the vector sum of the blade speed and wind speed, varies cyclically in both magnitude and direction.

According to the flow visualizations, we can obtain a qualitative study permitting the identification of dynamic stall phenomenon. We achieve this by using coloured dyes emission technique from the potential flow, the leading-edge and from the trailing-edge.

2. SIMILAR MOVEMENT

2.1 The model

Experimentations are made on a model, Fig. 1, with a NACA 0018 profile. For a rotation, the angle between the chord of the blade and the undisturbed potential flow is always constant. The chord is 6.0 cm and the rotational radius is 6.3 cm. Coloured dyes ejected from the leading-edge and the trailing-edge permit to show the boundary-layer and the wake of the blade.

2.2 Kinematic analogy

The kinematic [6] presented of the Darrieus wind turbine movement in Fig. 2-a is given by:

$$\lambda_E = \omega' R / V_\infty \tag{1}$$

$$\alpha_E = \arctan\left[\sin\theta / (\lambda_E + \cos\theta)\right] \tag{2}$$

$$|\, V_{REL} \,| = \omega' R \left[(1 + \cos\theta/\lambda_E)^2 + (\sin\theta/\lambda_E)^2\right]^{1/2} \tag{3}$$

The experimental model used has a similar movement to the Darrieus wind turbine. There is similarity between speeds. The kinematic of the experimental model is shown in Fig. 2-b:

$$\lambda_M = U_\infty/\omega r \tag{4}$$
$$\alpha_M = \arctan [\sin\theta/(\lambda_M + \cos\theta)] \tag{5}$$
$$| U_{REL} | = U_\infty [(1 + \cos\theta/\lambda_M)^2 + (\sin\theta/\lambda_M)^2]^{1/2} \tag{6}$$

Therefore, for the similarity between the wind turbine and the model, we have:

$$V_\infty \text{ (wind turbine)} = \omega r \text{ (model)} \tag{7}$$
$$\omega' R \text{ (wind turbine)} = U_\infty \text{ (model)} \tag{8}$$

However curvature effects in the similar motion are less significant with respect to Darrieus rotor because the relative frame rotation vanishes in the similar motion.

2.3 Parametrical study

Here is the list of dimensionless [6] variables which control the flow around the rotating blade:

WIND TURBINE

$$\lambda_E = \omega' R/V_\infty \tag{9}$$
$$Rey_E = \omega R c'/\nu_E \tag{10}$$
$$s_E = Nc'/R \tag{11}$$
$$\alpha_E = \tan^{-1} \left(\sin\theta/(\lambda_E + \cos\theta) \right) \tag{12}$$
$$k_E = c'\omega'/V_{REL} \tag{13}$$

EXPERIMENTAL MODEL

$$\lambda_M = U_\infty/\omega r \tag{14}$$
$$Rey_M = U_\infty c/\nu_M \tag{15}$$
$$s_M = Nc/r \tag{16}$$
$$\alpha_M = \tan^{-1} \left(\sin\theta/(\lambda_M + \cos\theta) \right) \tag{17}$$
$$k_M = c\omega/U_{REL} \tag{18}$$
$$K^* = c\omega/U_\infty$$

3. EXPERIMENT FACILITIES

3.1 The IMST hydrodynamic tunnel

The hydrodynamic tunnel of vertical axis with square section is entirely made of plexiglass (tunnel and convergent), and acting by gravity in a continuous mode [9].

The water is pumped in a first tank (2500 litres) and also in a superior tank (2500 litres). Once this operation is done, the opening of a flow control valve with electromechanical control induces the flow in the experimental tunnel because of gravity. The flow is then directed towards a recuperation tank.

The superior tank is connected to the experimental tunnel (section 20 cm x 20 cm, length 120 cm) by a convergent having a ratio of contraction of 15 to 1. The convergent is profiled in a manner to assure a progressive increase of the dynamic pressure as for as the opening of the experimental tunnel. Tranquillizer devices are installed at the entry of the convergent (honeycomb, fine mesh grill).

A complete circuit of filtration, softener and sterilization treats water to have it sterile.

Pressure outlets were installed on the water tunnel in order to determine the flow velocity. Throughout this study, the flow velocity is of 17 cm/s. This speed was later on verified by the Laser-Doppler-Velocimetry.

Previous studies have shown that there did not seem to have the gradient of speed in the way of the flow, that there is a correct profile of laminar flow, which average speed is in agreement with the speed of the flow. The relative intensity of turbulence for the average speed is inferior to 0.5%, which is acceptable.

3.2 Visualization methods

We can observe different parts of the flow, non perceptible or with too fugitive characteristics [9-10].

Notice first on the pictures taken, we observe a quadrant used for reference indicating θ every 30° on the rotational circle and shows on Fig. 2.

The colourings used permitting visualization of the flow are the hydrosoluble fluorescein for green filaments, red Congo for red filaments and rhodorsil E.I.P. for white filaments.

Six pipets positioned in upflow of the tunnel, permitting the obtention of non perturbed emission lines, is used to visualize the potential flow. The boundary-layer, vortices of stall and the wake of the blade are observed with the emission of white colouring coming from leading-edge and an emission of green colouring originating from the trailing-edge.

The lighting of colourings is obtained by four flashes unlatched simultaneously at a chosen position of the blade. A particular method autorizing a quantitative study of the flow, consists in releasing simultaneously in a first part two white flashes and a moment after releasing simultaneously two red flashes. We then modulate the flow in time and in direction around the blade, due to the superimposed colourings.

4. EXPERIMENTAL RESULTS AND ANALYSIS

4.1 Experimental results

All experiments were done with a flow velocity of water of 17 cm/s in the hydrodynamic tunnel.

The quadrant drawn on the rotational circle of the blade in the hydrodynamic tunnel is to find the θ exact position of the blade, and it indicates all the $\theta = 30^\circ$. The zero of the circle is at the upflow point. Notice that the blade turns clockwise.

Pictures taken at about every $\theta = 20^\circ$ permitted us to identify the dynamic stall regions. Once these zones located, macro-photos were taken for displacements of approximately $\theta = 5^\circ$ of the blade, which give us all the details of dynamic stall.

It is important that in our series of photos, each picture comes from a different rotational cycle, in order to eliminate small irregularities and to recognize dominant features of the flow.

Experiments were conducted for rotational speeds of the blade of 8, 16, 24, 32, 40, 50, 60 and 70 rpm. The preferable speeds to study in this assortment are $\omega = 8$ rpm and $\omega = 16$ rpm with an angle of offset of the blade $\alpha_o = 0^\circ$. For these two specific rotational speeds we can obtain a visible boundary-layer and also a different wake. If $\omega > 16$ rpm, the boundary-layer and the wake are sensibly the same up to $\omega = 16$ rpm, except some vortices more accentuated and the formation of the dynamic stall is observable less longer. When ω is much more larger than 16 rpm, meaning around 50 rpm or 70 rpm, we obtain some very large vortices which sometimes intersect the blade, and falsify temporarily the boundary-layer. At such speeds, the blade is like a flat plate for which the area of interesting is for a very short period.

For a complete rotation with $\omega = 8$ rpm, we observe two regions of stall. Having one between $\theta = -90^\circ$ and $\theta = 0^\circ$ and a second one between $\theta = 120^\circ$ and $\theta = 180^\circ$. For $\omega = 16$ rpm, this speed being already large, we observe only the first stall between -90° and 0°, second being blured by vortices. Two cases were also studied with angles of offset α_0 of 28° and of -28° for $\omega = 16$ rpm.

Macro-photos were therefore taken for those chosen moments of the rotation of the blade:

For the case of $\omega = 8$ rpm Figs. 6 to 9, we have in the region of $\theta = -90^\circ$ to $\theta = 0^\circ$, an opposite flow which starts from the trailing-edge when $\theta = -60^\circ$ and raises up to the leading-edge which increases with θ. There is a weak stall at $\theta = -30^\circ$ $\alpha = 13^\circ$. Finally, we obtain a deep stall at $\theta = -15^\circ$ $\alpha = 16^\circ$. For $\theta = -60^\circ$ we have calculated theoretically $U_{REL} = 21.5$ cm/s (Fig. 3), $\alpha = 8^\circ$ (Fig. 4). And for $\theta = -15^\circ$ we have a $U_{REL} = 19$ cm/s (Fig. 3), $\alpha = 16^\circ$ (Fig. 4) the local reduced frequency $k = 0.27$ (Fig. 5).

On Figs. 10 to 13 in the area of $\theta = 150^\circ$ to $\theta = 190^\circ$ where $\omega = 8$ rpm, there is for $\theta = 150^\circ$ ($\alpha = 17.5$ °) a beginning of boundary layer separation until leading-edge with the formation of a bubble at the leading- edge. Then, vortices are released and provoke a weak stall after $\theta = 170^\circ$ ($\alpha = 17^\circ$) where we have the maximum lift coefficient when the first bubble is at the half of the chord. We go through a strong stall since $\theta = 190^\circ$ for a short period after which the boundary-layer is very rapidly reattached, due to a large decrease of the angle of attack and a relative acceleration. According to calculations of Figs. 3, 4 and 5, we have tabulated values in Table 1.

Figs. 14 to 17 show the flow visualization in the region of $\theta = -50^\circ$ to $\theta = 10^\circ$, with a $\omega = 16$ rpm. A reversed flow is produced at $\theta = -50^\circ$ ($\alpha = 15^\circ$) and goes to half of the chord when $\theta = -30^\circ$, and at this moment the reversed flow goes up to the leading-edge very rapidly, a vortex is emitted by the bubble at the leading-edge, and simultaneously an other at the trailing-edge. We therefore have a weak dynamic stall for $\theta = -10^\circ$ ($\alpha = 29^\circ$) and a deep dynamic stall until $\theta = 10^\circ$ ($\alpha = 34^\circ$). Values are tabulated in Table 1.

For comparison purposes, tests were redone with angles of offset. We first notice that the fact to give an angle of offset to our blade, puts out of phase the dynamic stall on the rotational circle. On Figs. 18 to 21 where $\omega = 16$ rpm and $\alpha_0 = 28^\circ$, we have the stall in the area of $\theta = 210^\circ$ to $\theta = 270^\circ$.

For other tests where $\omega = 16$ rpm and $\alpha_0 = -28^\circ$, there is a dynamic stall in the region of $\theta = 30^\circ$ to $\theta = 70^\circ$, see Table 1 for values. A reverse flow arising from the trailing-edge at $\theta = 30^\circ$, progresses up to the leading-edge, a bubble forms at the leading-edge at $\theta = 60^\circ$ and we have a weak stall at $\theta = 70^\circ$, at the time where the boundary-layer reattaches because U_{REL} and α

are decreasing too much. In this case there is no deep stall. Over $\theta = 70°$ it is the other side of the blade which undergoes the same kind of detachment of the boundary-layer bringing another stall due to a very rapid change of the flow between upper surface and lower surface.

4.2 Analysis

Cases with the angle of offset are identical with the case without angle of offset, except for the existence of a shift of phase for stalls on the rotational circle. The chosen angle of offset in terms of the rotational speed gives an out of phase of 90° for the angle of attack α. We know therefore that α_o does not affect the occuring of the stall, but rather the position where it forms.

The formation of dynamic stall can be different, depending of operating conditions. First of all, there is the case where a reverse flow to the trailing-edge goes up to the leading-edge in order to form a bubble of vortices emission at the leading-edge, it increases and when it reaches half of the chord, we have maximum lift, when the vortex reaches over half of the chord, a weak stall occurs, followed by a deep stall if the parameters are increasing too much.

And, in the second case of formation of dynamic stall, we observe a reverse flow arising from the trailing-edge, but when its ascension has reached about half of the chord, there is sudden appearance of two vortices, one at the leading-edge and the other at the trailing-edge. All this without been able to observe the reverse flow until the leading-edge and the formation of bubble of vortices emission at the leading-edge.

A special configuration of sudden reattachment is observed, Fig. 18, when the incidence angle becomes zero and the motion acceleration is significant. In this case the luminar boundary layers thickness is reduced and the wake structures are vanishing. The blade cuts the external emission lines with a low disturbance in a low drag configuration.

Furthermore, analysis of the unsteady Kutta-Joukowski condition show non linear unsteady effects induced by the boundary layers behaviour. In this way the wake emission either along the upper or the lower surface, presents a shift with the circulation variation in time, according the boundary layers behaviour.

The analysis of the flow around a blade in a similar motion by comparison with the Darrieus motion show nonlinear unsteady effects into the boundary layer and on the wake. For both motions, the stall is obtained depending on the tip-speed ratios λ_E and λ_M respectively.

However, the streamlines curvature appears to be less important for the similar motion as predicted. The wake kinematic is quite different inducing interaction in the same kind. For example, the stall, when it does, occurs twice in the upstream and in the downstream regions. For the similar motion, the stall downstream is less affected by interaction between the blade and the vortex wake as for the Darrieus motion.

In the end, caution has to be consider, using this qualitative analysis, in the way that bloccage effects in the water tunnel are not negligeable, and only low Reynolds numbers have been obtained in order of magnitude of 10^4.

5. CONCLUSIONS

The flow around a blade animated by a similar motion to the Darrieus turbine has been analysed by visualization.The unsteady effects have been pointed out, especially concerning the boundary layer behaviour, the Kutta-Joukowski condition and the stall development. The kinematic of the blade wake is similar for example concerning a vortex counter rotating doublet when the stall occurs but different rotation entrainment effects reduce the interaction effects in the similar motion.

In the two cases, nonlinear unsteady effect have been observed even the reduced frequency is low because of the flow interaction and the entrainment loading.

Understanding these phenomena improve the ability to propose stall calculation models adapted to the specific motions considered.

ACKNOWLEDGEMENT

This work was supported by NSERC Grant No. A-4556 and by IMST budget for the experimentations.

REFERENCES

1. Brochier, G., Paraschivoiu, I., "Etude de la couche limite instationnaire", IREQ, Varennes, Québec, Canada, 1985.

2. Mehta, Unmeel B., "Dynamic stall of an oscillating airfoil", Ames Research Center, NASA, Moffett Field, Calif., U.S.A.

3. Michel, R., Cousteix, J., Houdeville, R., "Unsteady turbulent shear flow", IUTAM Symposium Toulouse, France, 1981.

4. D., P. Telionis, "Unsteady viscous flows", Springer- Verlag, New-York inc., U.S.A., 1981.

5. Favier, D., Maresca, C., Rebont, J., "Dynamic stall due to fluctuations of velocity and incidence", IMF, CNRS, Marseilles, France, 1982.

6. Laneville, A., Vittecoq, P., "Simulation de l'écoulement autour d'un profil de pale d'un rotor Darrieus à axe vertical dans des conditions de décrochage et mesure de la distribution de pression", Univ. de Sherbrooke, 1983.

7. Clayton, B.R., Moris, Y.S.M., "Unsteady aerodynamics related to vertical axis rotors", BWEA, England.

8. Couchet, G., "Les profils en aérodynamique instationnaire et la condition de Joukowski", Librairie scientifique et technique Albert Blanchard, Paris 6^e, France, 1976.

9. Domptail, C., Bonmarin, P., Dumas, R., "Visualisation des structures instationnaires dans un écoulement turbulent, en aval d'un et de deux barreaux parallèles", IMST, Université d'Aix-Marseilles II, France, 1978.

10. McAlister, K.W., Carr, L.W., "Water tunnel visualizations of dynamic stall", ASME Journal, Ames Research Center, Moffett Field, Calif., 1978.

11. Fraunié, P., Béguier, C., Paraschivoiu, I., "Importance du décrochage dynamique dans les calculs aérodynamiques du rotor Darrieus", J. de mécanique théorique et appliquée, Vol. 4, No. 6, 1985.

12. Brochier, G., Fraunié, P., Béguier, C., Paraschivoiu, I., "Water Channel Experiments of Dynamic Stall on Darrieus Wind Turbine Blades", J. of Propulsion and Power of AIAA, Vol. 2, No. 5, 1986, pp. 445-449.

LIST OF FIGURES

Fig. 1 Picture of the model

Fig. 2 a) The kinematic of a wind turbine
b) The kinematic of the experimental model

Fig. 3 Flow velocity on the experimental model vs azimuthal angle

Fig. 4 Local angle of attack vs azimuthal angle

Fig. 5 Reduced frequency for the experimental model vs azimuthal angle

Fig. 6 to 21 Visualizations of the experimental model

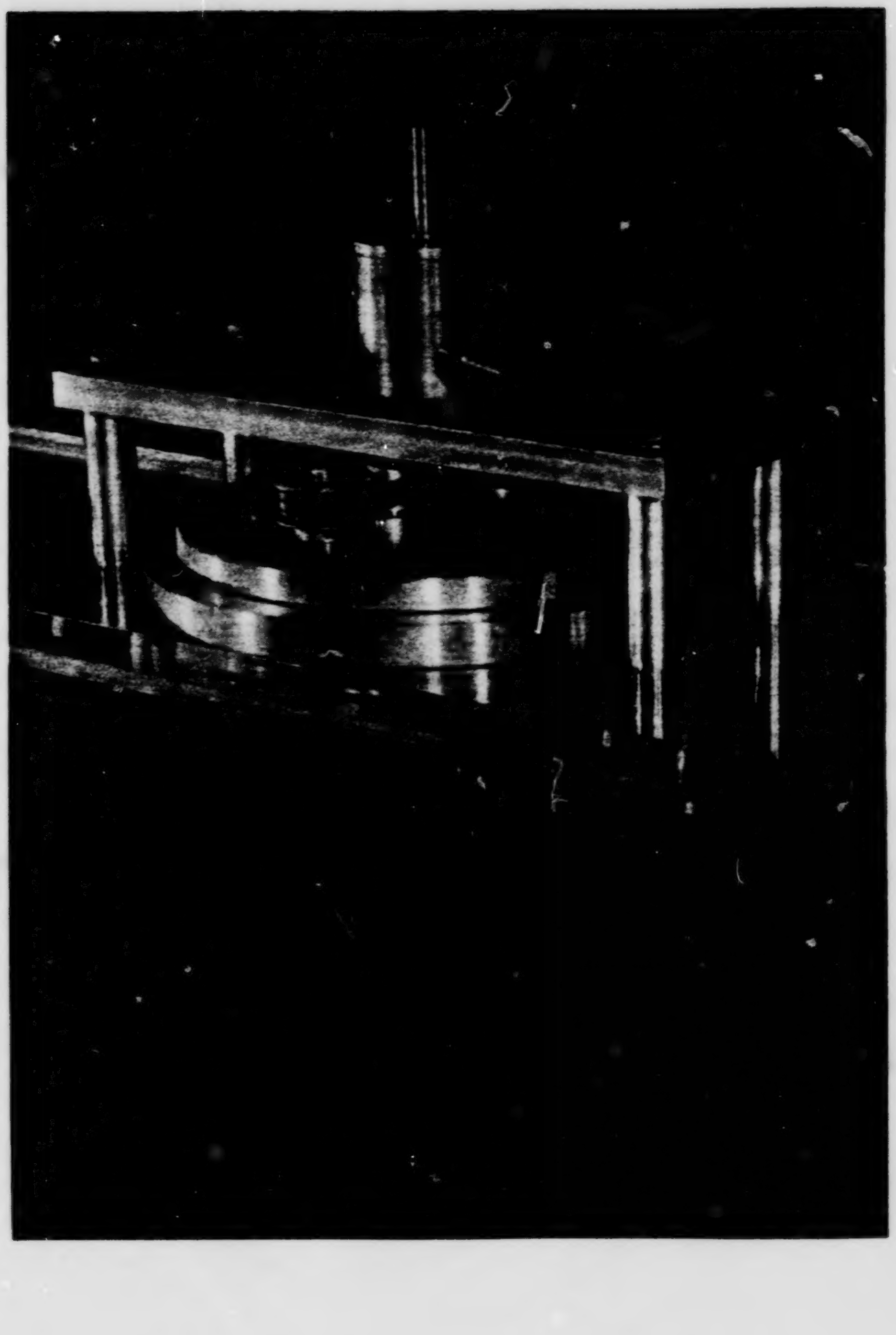
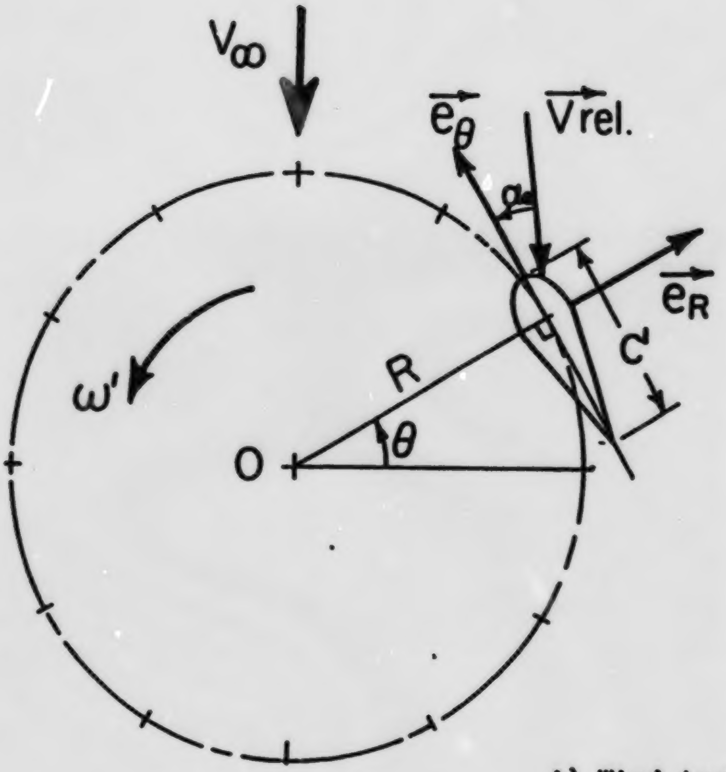
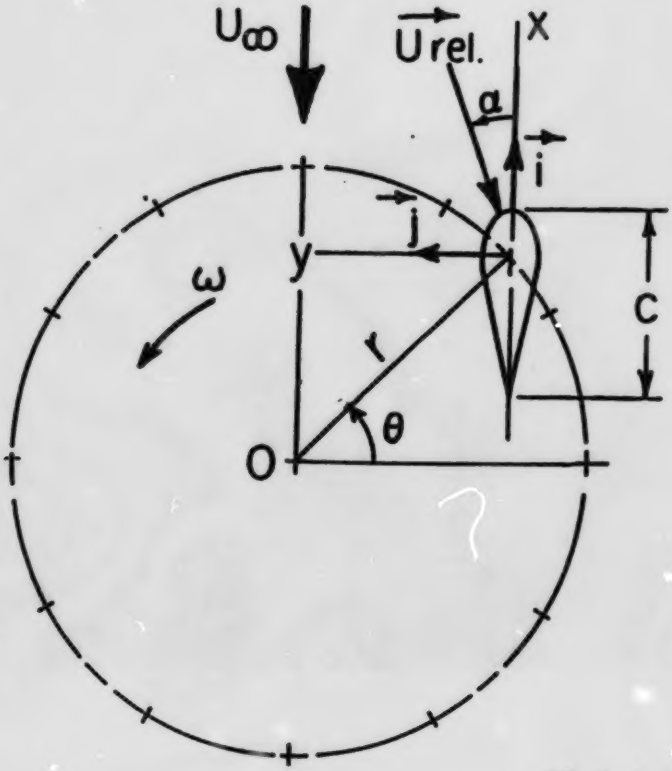


Fig. 1


V_∞
$\vec{e_\theta}$
$\vec{V}$rel.
α
$\vec{e_R}$
C'
ω'
R
θ
O

A) Wind turbine


U_∞
$\vec{U}$rel.
X
α
$\vec{i}$
$\vec{j}$
y
ω
C
r
θ
O

B) Model

Fig. 2

Urel VS theta (deg)

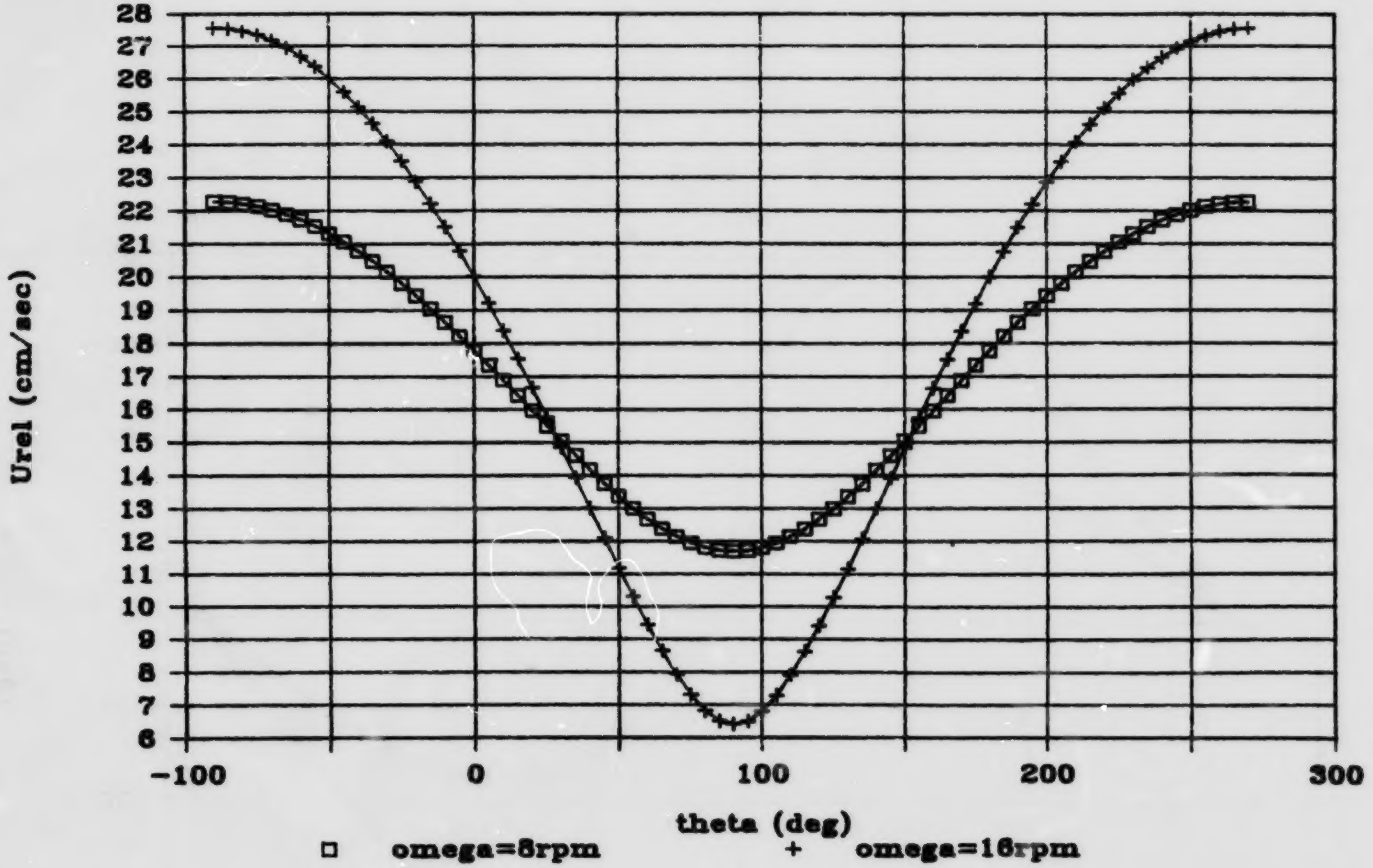


Fig. 3

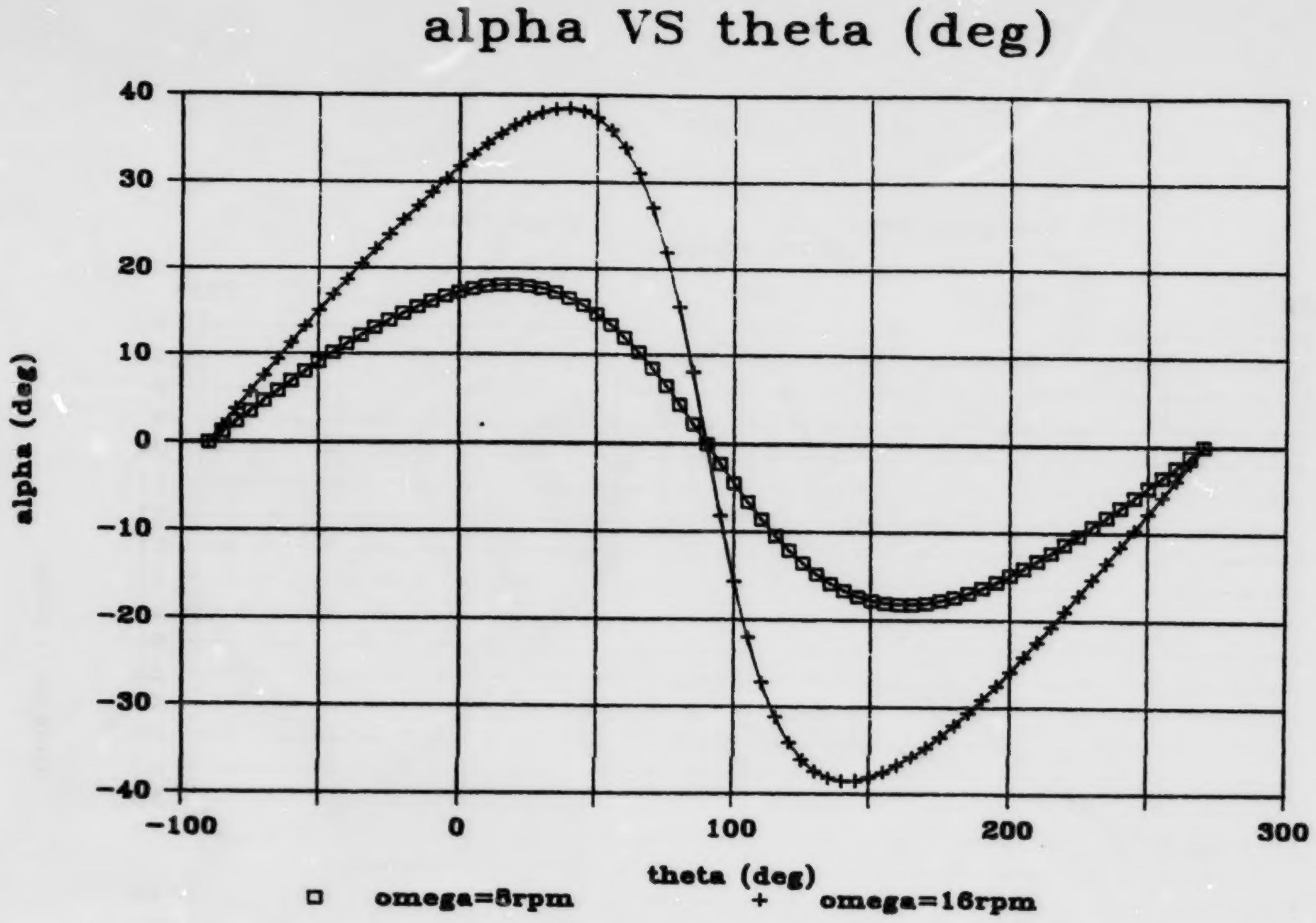

alpha VS theta (deg)
alpha (deg)
40
30
20
10
0
−10
−20
−30
−40
−100
0
100
200
300
theta (deg)
□ omega=8rpm
+ omega=16rpm

Fig. 4

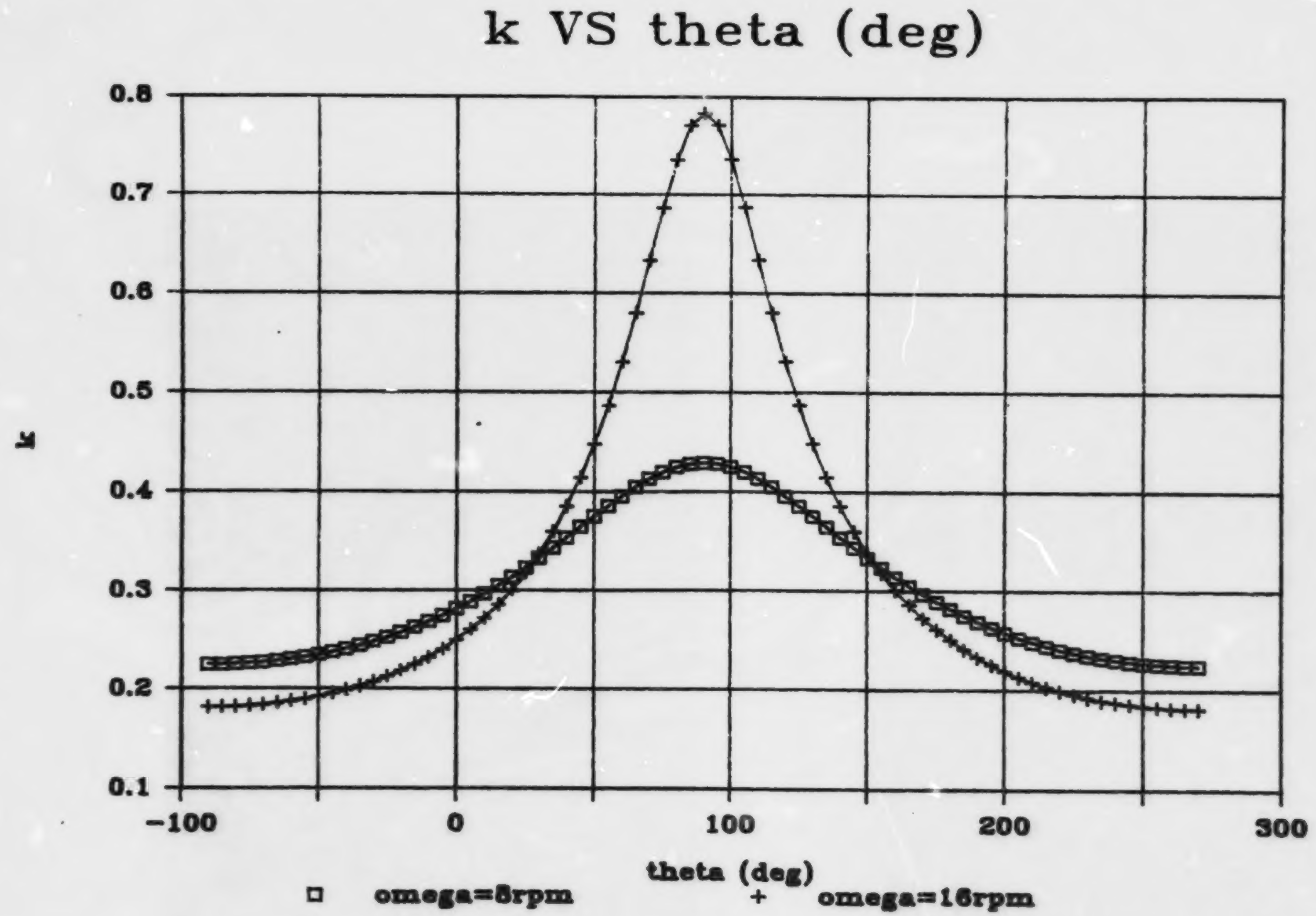
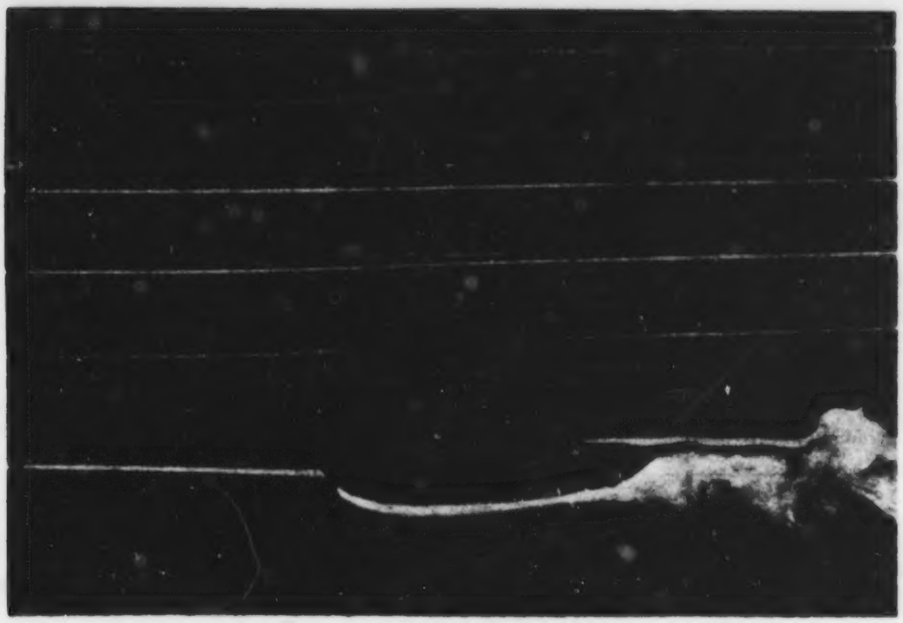
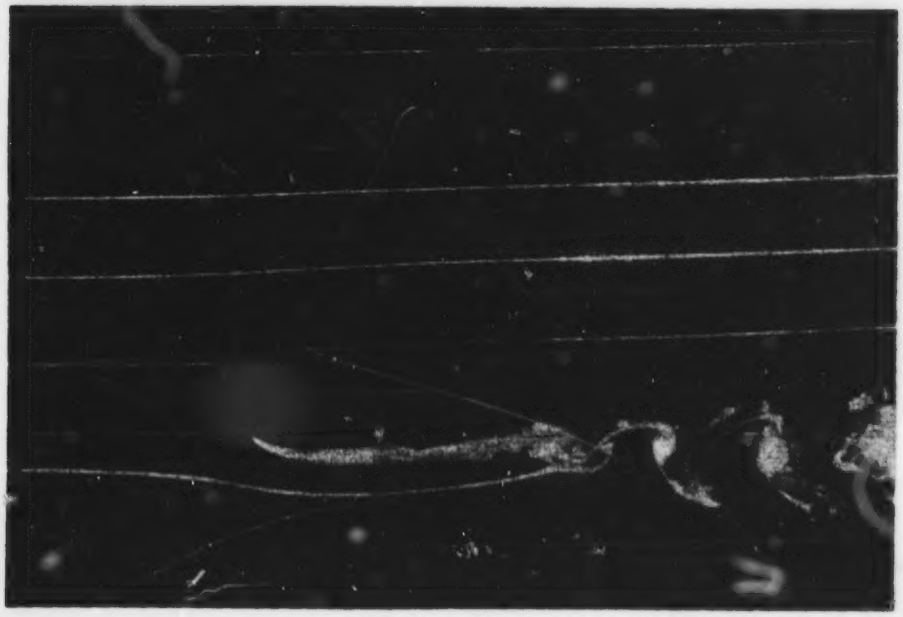

k VS theta (deg)
k
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
−100
0
100
200
300
theta (deg)
□ omega=8rpm
+ omega=16rpm

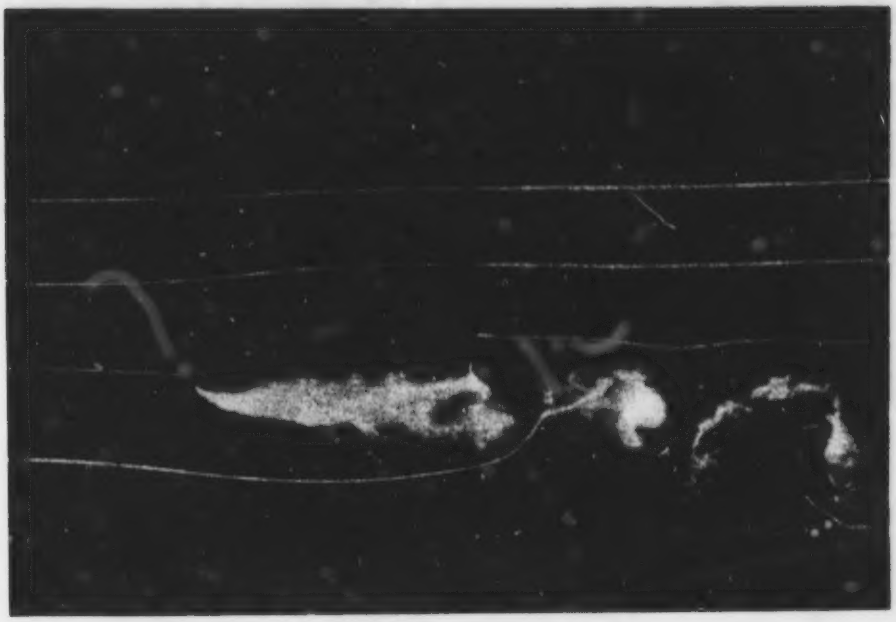
Fig. 5



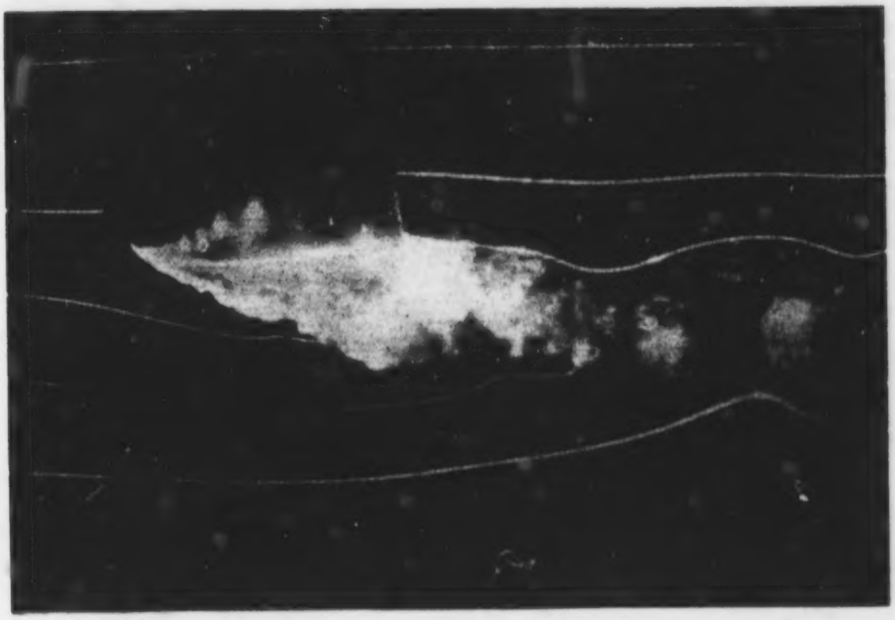
α_o = 0° ω = 8rpm U_∞ = 17cm/s Θ = -60° Fig.: 6



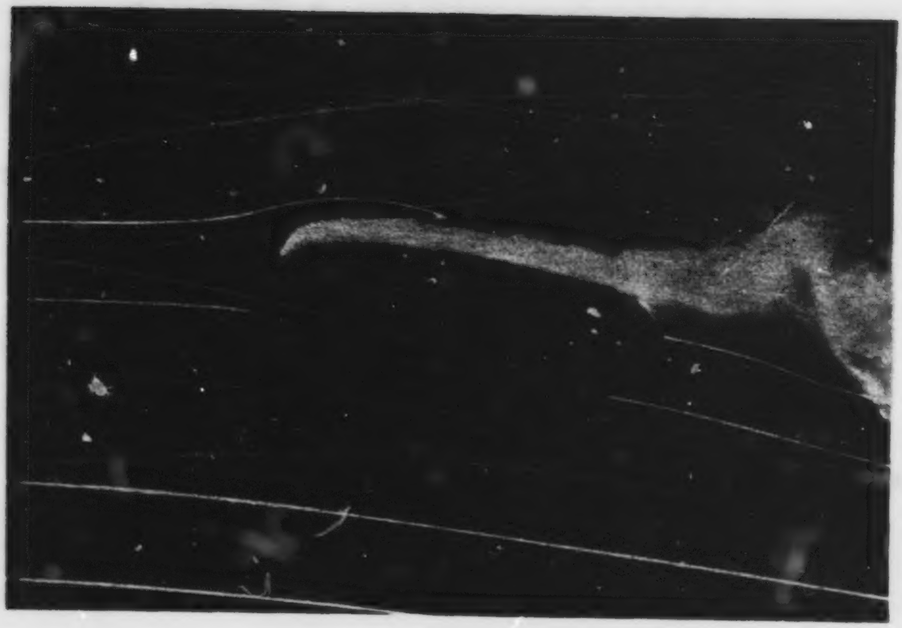
α_o = 0° ω = 8rpm U_∞ = 17cm/s Θ = -40° Fig.: 7



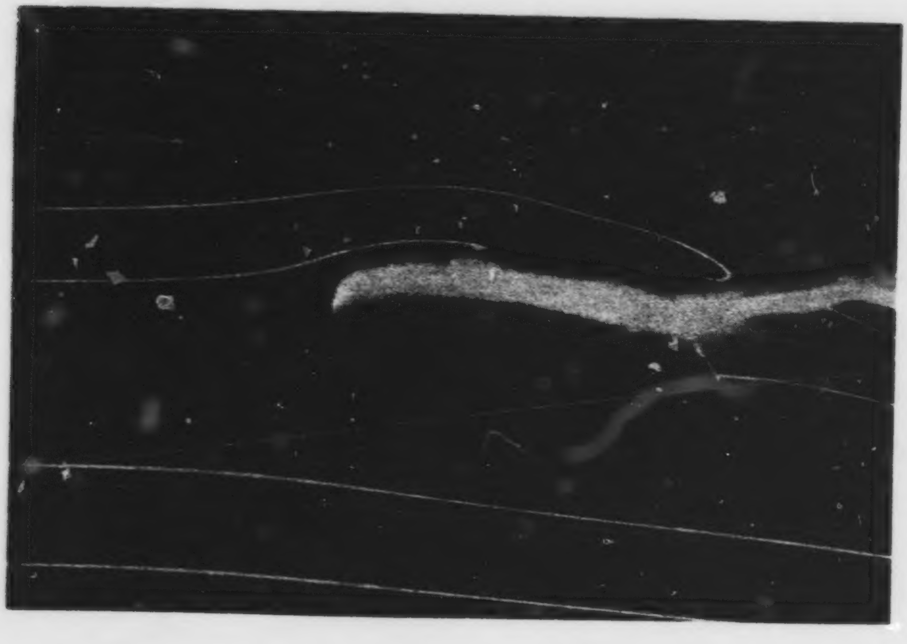
$\alpha_\infty = 0^\circ$ $\omega = 8\text{rpm}$ $U_\infty = 17\text{cm/s}$ $\Theta = -20^\circ$ fig.: 8



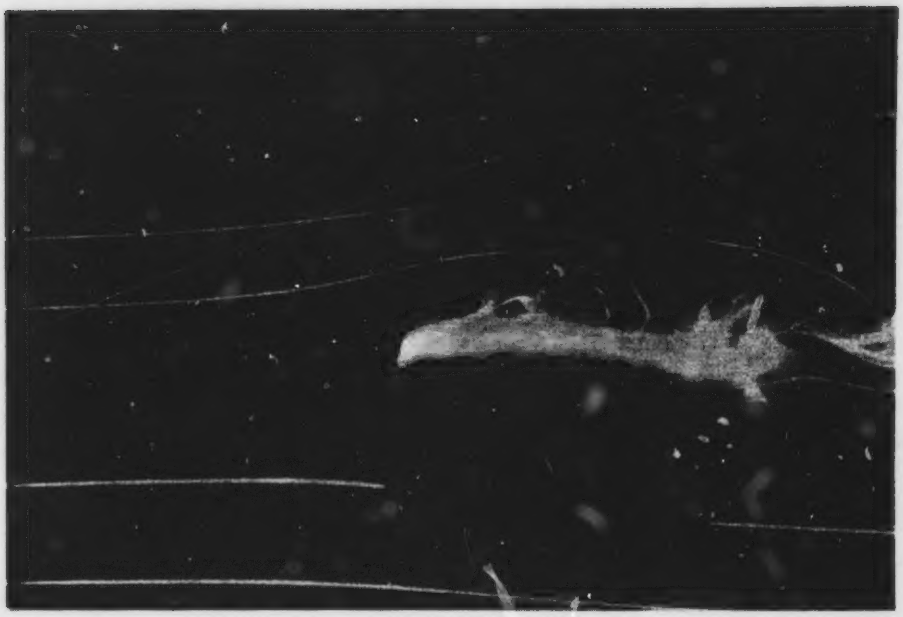
$\alpha_\infty = 0^\circ$ $\omega = 8\text{rpm}$ $U_\infty = 17\text{cm/s}$ $\Theta = 0^\circ$ fig.: 9



$\alpha_o = 0°$ ω = 8rpm U_∞ = 17cm/s Θ = 150°   fig.: 10



$\alpha_o = 0°$ ω = 8rpm U_∞ = 17cm/s Θ = 160°   fig.: 11

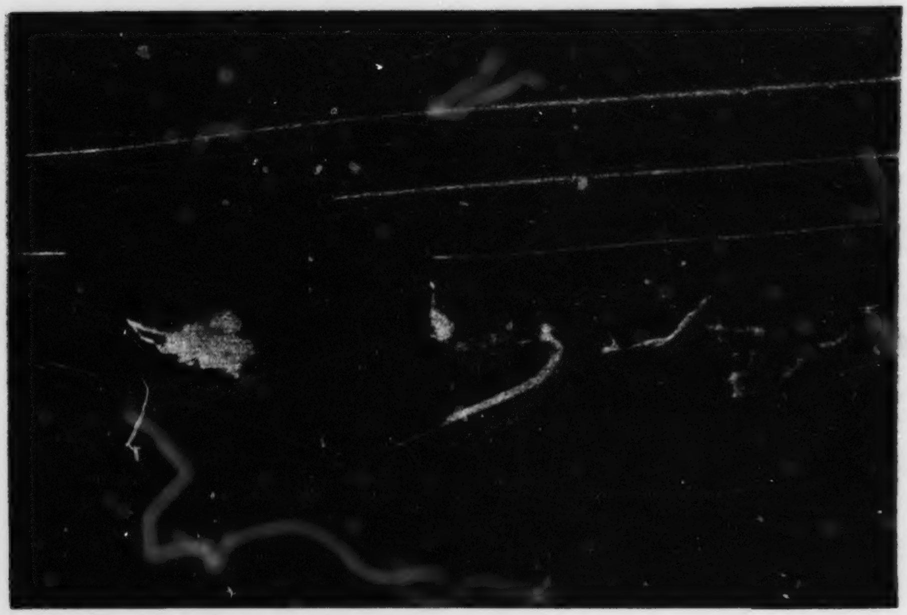


α_o = 0° ω = 8rpm U_∞ = 17cm/s θ = 170°   fig.: 12

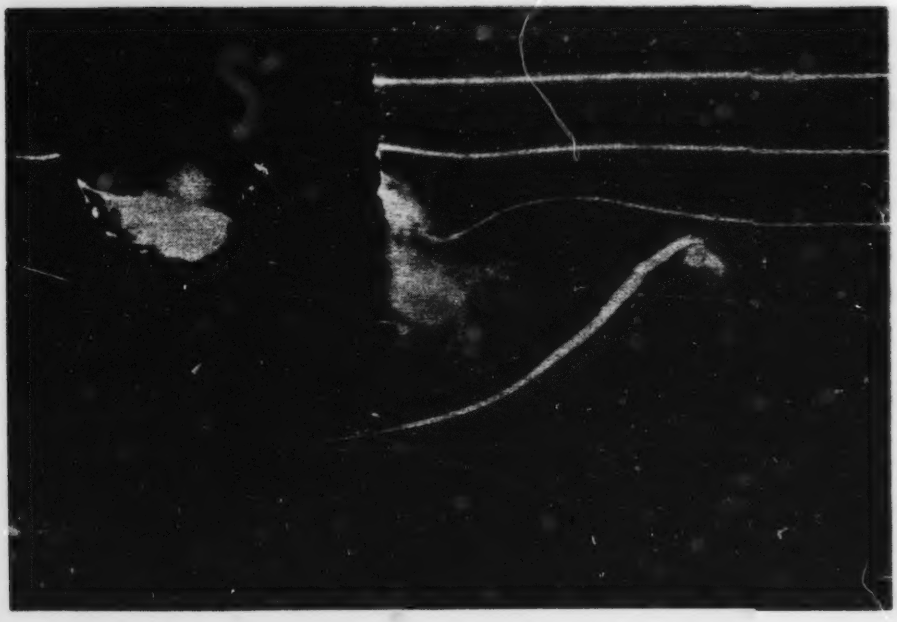
α_o = 0° ω = 8rpm U_∞ = 17cm/s θ = 190°   fig.: 13

$\alpha_o = 0°$ $\omega = 16rpm$ $U_\infty = 17cm/s$ $\theta = -50°$ fig.: 14

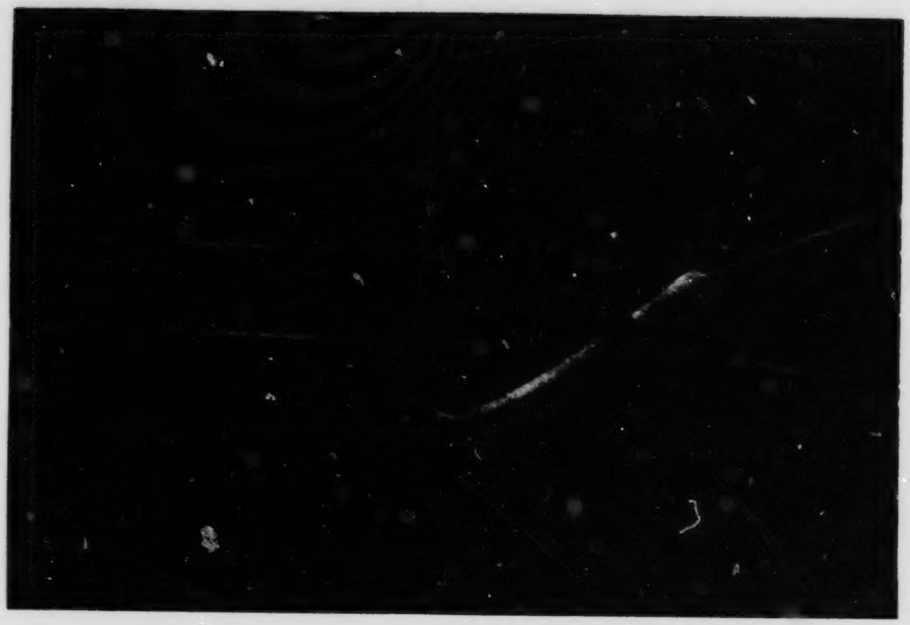
$\alpha_o = 0°$ $\omega = 16rpm$ $U_\infty = 17cm/s$ $\theta = -30°$ fig.: 15



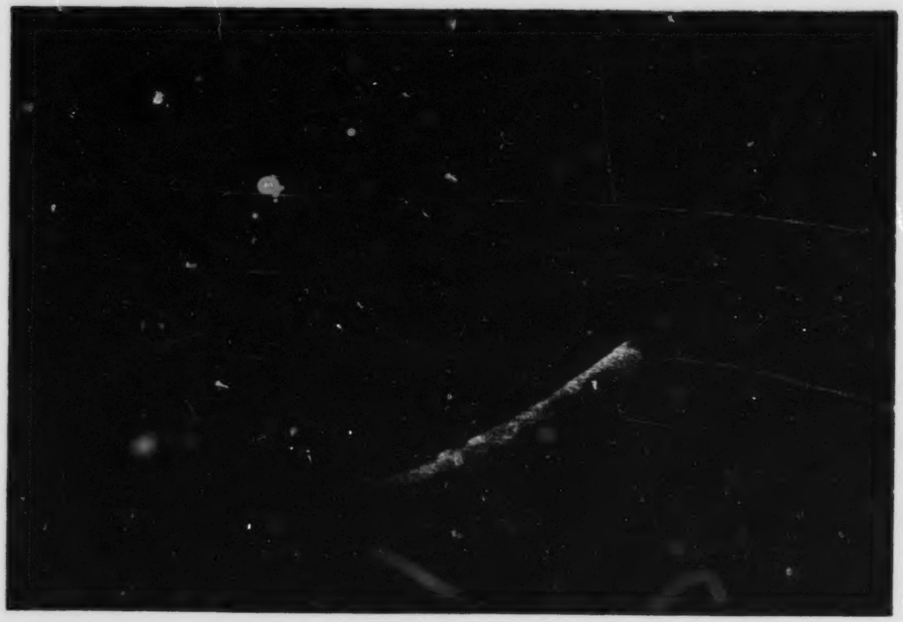
$\alpha_0 = 0^\circ$ $\omega = 16\text{rpm}$ $U_\infty = 17\text{cm/s}$ $\Theta = -10^\circ$ fig.: 16



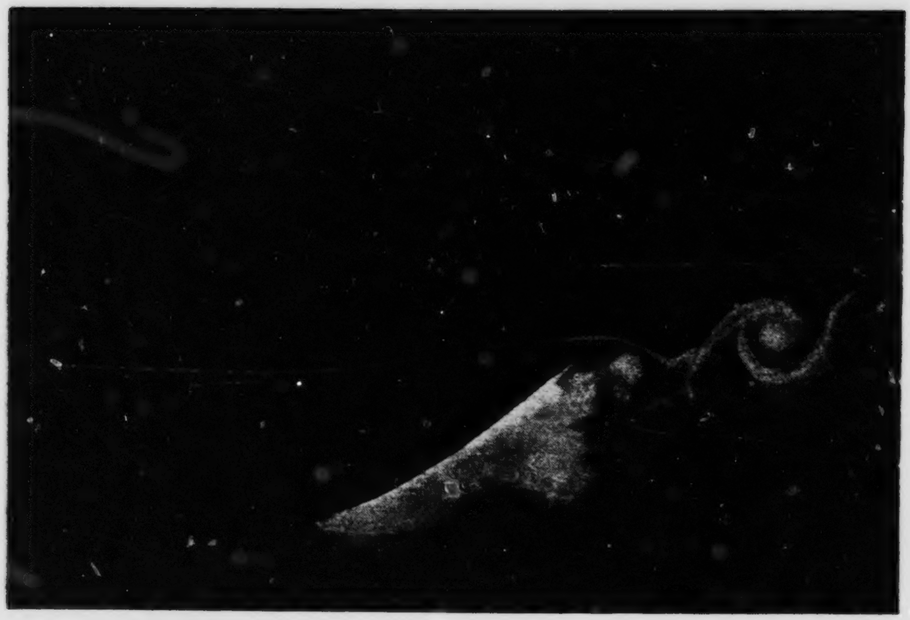
$\alpha_0 = 0^\circ$ $\omega = 16\text{rpm}$ $U_\infty = 17\text{cm/s}$ $\Theta = 10^\circ$ fig.: 17



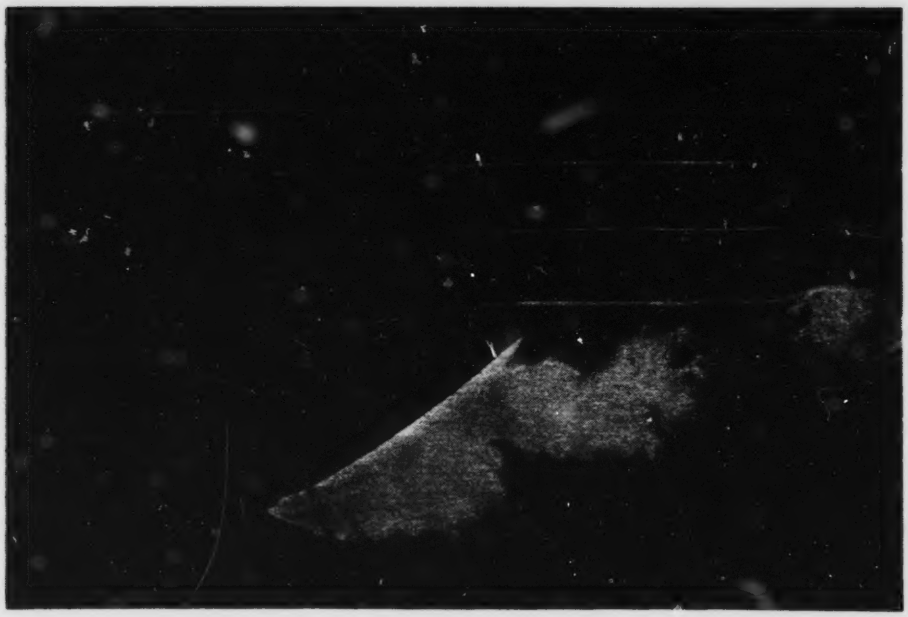
α_o = 28° ω = 16rpm U_∞ = 17cm/s Θ = 220° fig.: 18



α_o = 28° ω = 16rpm U_∞ = 17cm/s Θ = 240° fig.: 19



α_0 = 28° ω = 16rpm U_∞ = 17cm/s θ = 260° fig.: 20



α_0 = 28° ω = 16rpm U_∞ = 17cm/s θ = -80° fig.: 21

CANWEA 1986
Quebec City, Quebec

October 27-28, 1986

ATLANTIC WIND TEST SITE ACTIVITIES

Abstract

The Atlantic Wind Test Site (AWTS) was established in Canada in 1981 to provide Canada with a facility to test and to aid in the development of wind related technology for Canadian application. This paper describes the site facilities, current and recent projects and discusses future activities and directions for the site.

Introduction

The AWTS is located at the extreme northern tip of Prince Edward Island in Canada (Figure 1). It consists of 185 acres of flat terrain bordered by a low cliff and exposed through 300 degrees to the Gulf of St. Lawerence (Figure 2).

The site is exposed to a typical Canadian marine environment with annual temperature ranges of +/- 30 deg. C, average windspeeds of 6.25 m/sec and has considerable salt corrosion.

The Institute of Man and Resources designed and now operates the site under a ten year operating agreement with the government of Canada. Funding for the site is provided by paying clients and is supplemented by an annual contribution from the department of Energy Mines and Resources.

Facilities and Staff

The test site has a main building that provides an operations centre for site activities. This earth sheltered lab houses the electronics lab, data processing centre, office space and emergency accommodations.

A mechanical shop located near the main building is equipped with typical maintenance and simple fabrication work.

The test site is arranged to allow tests to a number of machines simultaneously. The test pads run in a southwesterly direction across the site and are serviced by a 600 V 3 phase utility line that passes each site. Each site has a small building to house switching equipment and instrumentation .

The site has four full time staff members who carry out the wide range of work necessary.

Data Acquisition System

A new data acquisition system has been purchased and commissioned at the AWTS in early 1986. The new system consists of several field located data loggers with on board monitoring and data processing capabilities connected by an FM telemetry link to a base station IBM-AT microcomputer in the main laboratory building.

The field data loggers are Campbell Scientific CR21XL microloggers. These state of the art units are capable of monitoring up to 16 single voltage input channels as well as four pulse input channels. It provides signal conditioning for volts, millivolts, DC/AC resistance, thermistor linearization and RH sensor linearization. It can also provide constant analog output channels, excitation for resistive bridge measurements and six digital control ports to control external devices. The logger can sample a full number of inputs at a preselectable scan rate and either store the raw data or perform preprogrammed standard data processing functions. This data, either raw or processed, may then be stored in final memory for manual interrogation or transmitted to the main computer.

The IBM-AT is equipped with appropriate software and hardware to enable automatic retrieval and processing of the data from the loggers on a daily basis and to retain the results on its 30 megabyte hard disk until the data is examined by the site data technician and appended to an appropriate test file.

The data may also be examined on a real time basis.

This new data system has reduced the operator requirements dramatically while also improving accuracy and reliability. It also provides reasonable protection from lightning.

For dynamic analysis the new data loggers have the capability of performing both high speed sampling and Fast Fourier Transformations (FFT).

Additional dynamic analysis can be done on the Hewlett Packard HP 1000 computer on loan to AWTS from the National Research Council of Canada for evaluation of a Indal 500 kW under study at AWTS.

Projects

1. AES Anemometer Comparison

This test has been completed some time ago and the final report is due shortly. Eight different pairs of anemometers were compared over a period of several years. Prices ranged from $50 to $2500 US per unit. The test results are particularly interesting in that the least expensive unit tested was a consistently high performer in reliability that had acceptable accuracy over the period of the test.

2. Canadian Standards Association (CSA) Confirmation Test

CSA, in conjunction with various government and private institutions in Canada, has been developing standards for Canadian application of wind turbines over the past several years.

A subcommittee has recently completed a preliminary Performance Standard and prior to acceptance a field test was requested to confirm the applicability of the standard.

AWTS has conducted tests on two sections of the standard, the utility grid connected WECS and the battery charging WECS.

The CSA standard on performance evaluation is very similar to the IEA and AWEA standards with some exceptions (see Appendix A for excerpts from CSA F417 - Wind Energy Conversion Systems, Performance); the minimum data base requirements are based on a statistical evaluation rather than on an arbitrary number of points for each bin. Also the CSA standard addressed water pumpers and battery charging WECS separately from grid connected WECS.

3. Aquilo (Figure 3) - A 500 kW Vertical Axis Wind Turbine manufactured by Indal Technologies of Mississauga, Ont.

It is rated a 522 kW @ 19 m/sec. The rotor is 36mx24m and rotates at 45 rpm. It drives two 350 HP induction generators through a 16:1 spur gear single mesh speed increaser.

The unit has been installed at AWTS for several years and during the period of tests a number of operational problems have been resolved. The unit suffered a blade failure at the upper strut connection in Novermber 1985. The unit has been inoperational since then. The blade failure has been determined to be stress corrosion related and a modified strut design will alleviate the problem.

Reassembly of the unit will take place this fall and a new test program will be carried out on the modified structure.

4. Adecon Energy Systems

The Adecon 125 kW is a low cost external frame VAWT (Figure 4). The 17mx25m rotor sits in a free standing structure made from a lattice work of angle sections 12 metres above ground level. This external frame reduces bearing and torque tube sizes while reducing foundation and space requirements. The energy production is also increased by the raised rotor. The prototype has completed tests at AWTS.

A second generation Adecon unit incorporating some significant improvements is expected to be erected at AWTS this fall or winter for long term reliability tests.

5. Wind Diesel

Canada is fortunate to have substantial natural energy resources and as a result energy costs are quite low when compared to most of the world. However, much of Canada is sparsely populated and many remote communities are supplied by diesel generated electricity. It has be long been recognized that the most immediate application for wind technology in Canada will be in these remote communities where diesel generators are used and where a good wind regime often exists (Figure 5).

Considerable work has been done in Canada on wind/diesel research in the past number of years. A demonstration unit consisting of two 50 kW diesel generators, a 35 kW Indal VAWT supplying power to a simulated community demand load, has been successfully operated in both hybrid and autonomous modes and with the wind turbine coupled to the diesels both mechanically and electrically. This unit, originally installed at Sudbury, Ontario (Figure 6), has been disassembled and is presently being assembled at AWTS to continue testing.

Immediate plans are to recommission the machine to operate reliably in a wind only mode. Future development will attempt to optimize short and intermediate term storage for more effective autonomous operation.

6. Centre of Expertise

The AWTS has been recognized by the federal department of Energy Mines and Resources (EMR) as a "Centre of Expertise." This "open" contract enables the AWTS to provide technical assistance and advice to EMR and any company in the the wind energy field with such a requirement. Work is performed at the direction of EMR.

7. MBB - Monopteros

Thermax Canada has entered into an agreement with a German WECS manufacturer MBB to market their products in Canada. An MBB "Monopteros" 20 kW single blade turbine will be installed at AWTS shortly to undergo performance and reliability tests during the winter months.

Future Activities

Cutbacks by the Canadian government have virtually eliminated the National Research Council, which have played a key role in wind energy development, from the wind energy program in Canada. The department of Energy Mines and Resources now has the responsibility of administering the reduced program.

The result is much reduced activity in the wind energy sector. With the continuing pressure on government for fiscal restraint and the continuing low price of oil, it is unlikely renewable energy will get any increase in the foreseeable future.

However, despite a general decline in total wind activity in Canada, the work load at AWTS is starting to pick up and there is considerable optimism for the future.

Immediate work on the wind diesel and the Indal 500 kW will require substantial effort. The expected installation of the new Adecon unit and the Monopteros will further occupy the staff for at least the next six months. More significantly, the receipt of the wind diesel work and the centre of expertise contract suggest recognition of our technical capabilities and expertise and it is probable that significant additional work will be required to further develop the wind diesel concept and to otherwise support wind energy development.

Conclusion

Although no long term commitment exists, either for continued operation of the AWTS or even for continued funding for wind energy research in Canada, we at the AWTS are optimistic we will continue to operate and to contribute in an even more substantial manner than in the past. For the next year in particular, activity will be high in the wind diesel program and in product development with manufacturers of several of the scheduled units to be installed at AWTS.

REFERENCES

1. M.S. Chappell, Some Current Activities in the Canadian Wind Energy Program, Division of Energy, National Research Council of Canada Report No. 22774, October 1983, reprintd April 1984.

2. L.A. Schienbein, Sudbury Wind-Diesel Report, Design, Development and Testing of a Vertical Axis Wind Turbine Assisted Diesel Generator System, March 1984.

3. Stephen L. Bolcso, Wind Energy Resource Assessment Seminar, National Research Council of Canada Report No. TM-WE-003, November 1980.

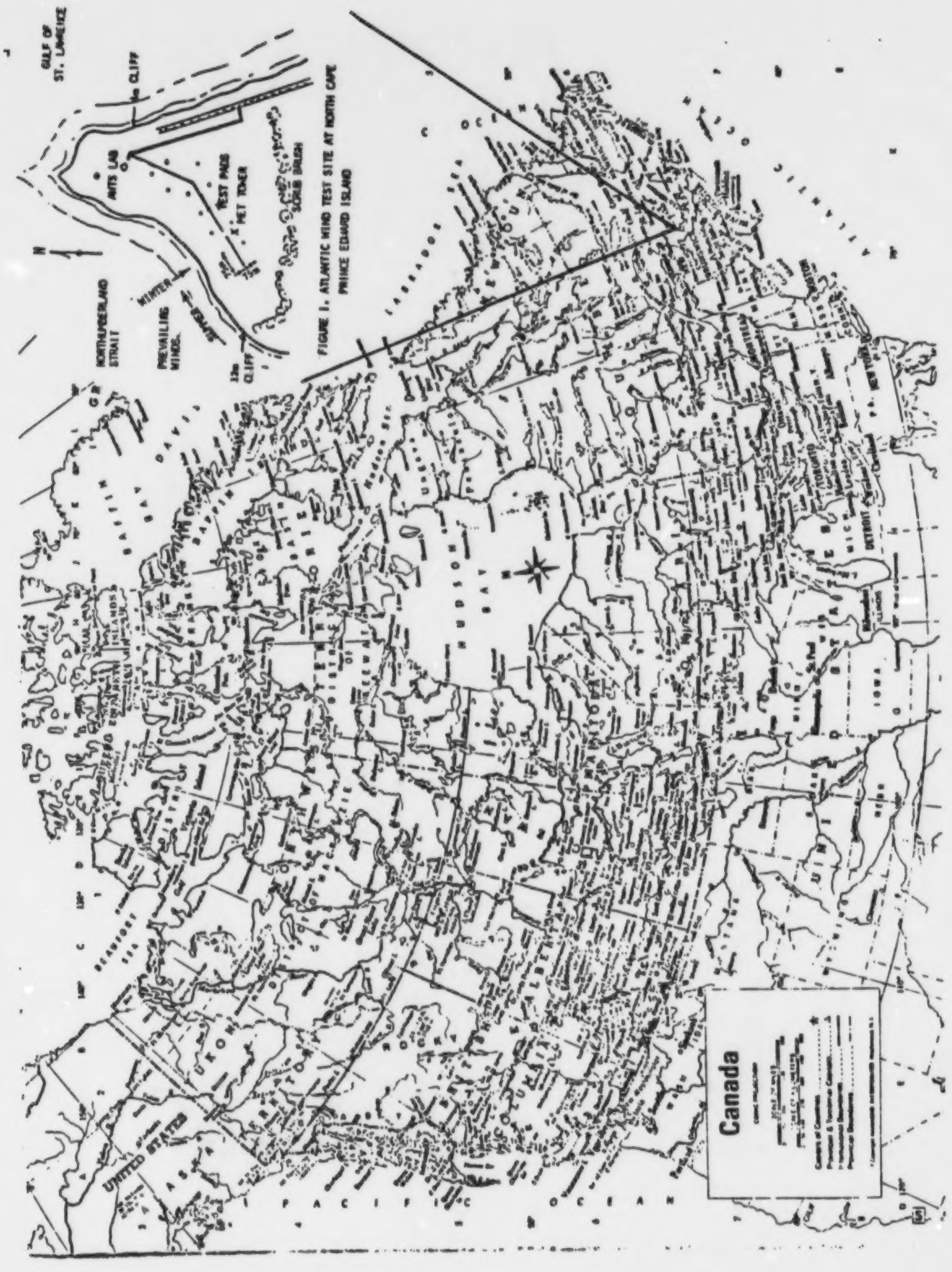

GULF OF ST. LAWRENCE
CLIFF
AWTS LAB
TEST PADS
MET TOWER
SCRUB BRUSH
N
NORTHUMBERLAND STRAIT
WINTER
SUMMER
PREVAILING WINDS
12m CLIFF
FIGURE 1. ATLANTIC WIND TEST SITE AT NORTH CAPE PRINCE EDWARD ISLAND
Canada
HUDSON BAY
BAFFIN BAY
DAVIS
LABRADOR SEA
ATLANTIC OCEAN
PACIFIC OCEAN
BEAUFORT SEA
ALASKA
UNITED STATES
YUKON
TORONTO
DETROIT
NEW YORK
IOWA

Figure. 1

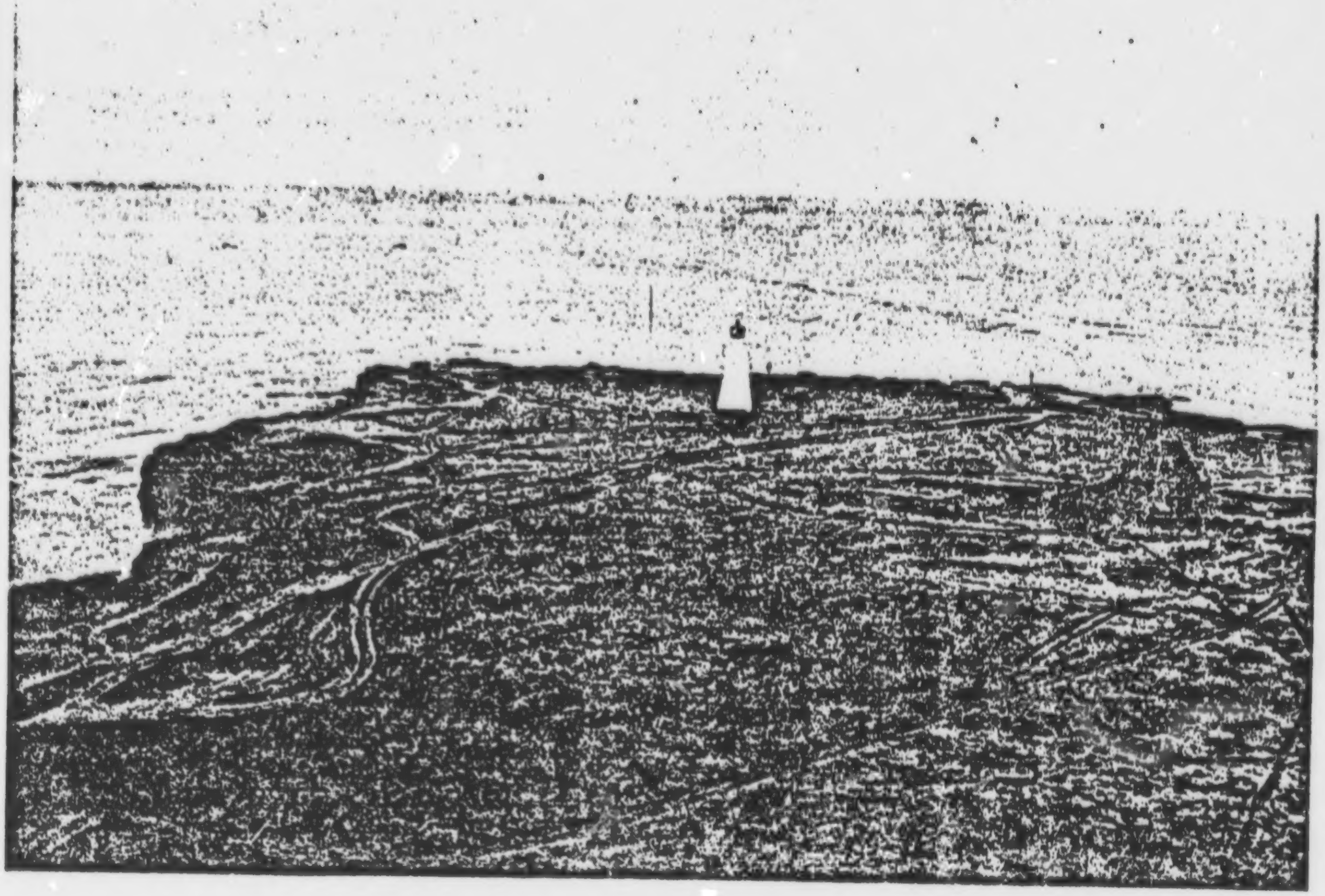


Figure 2. Aerial view of Atlantic Wind Test Site, Prince Edward Island

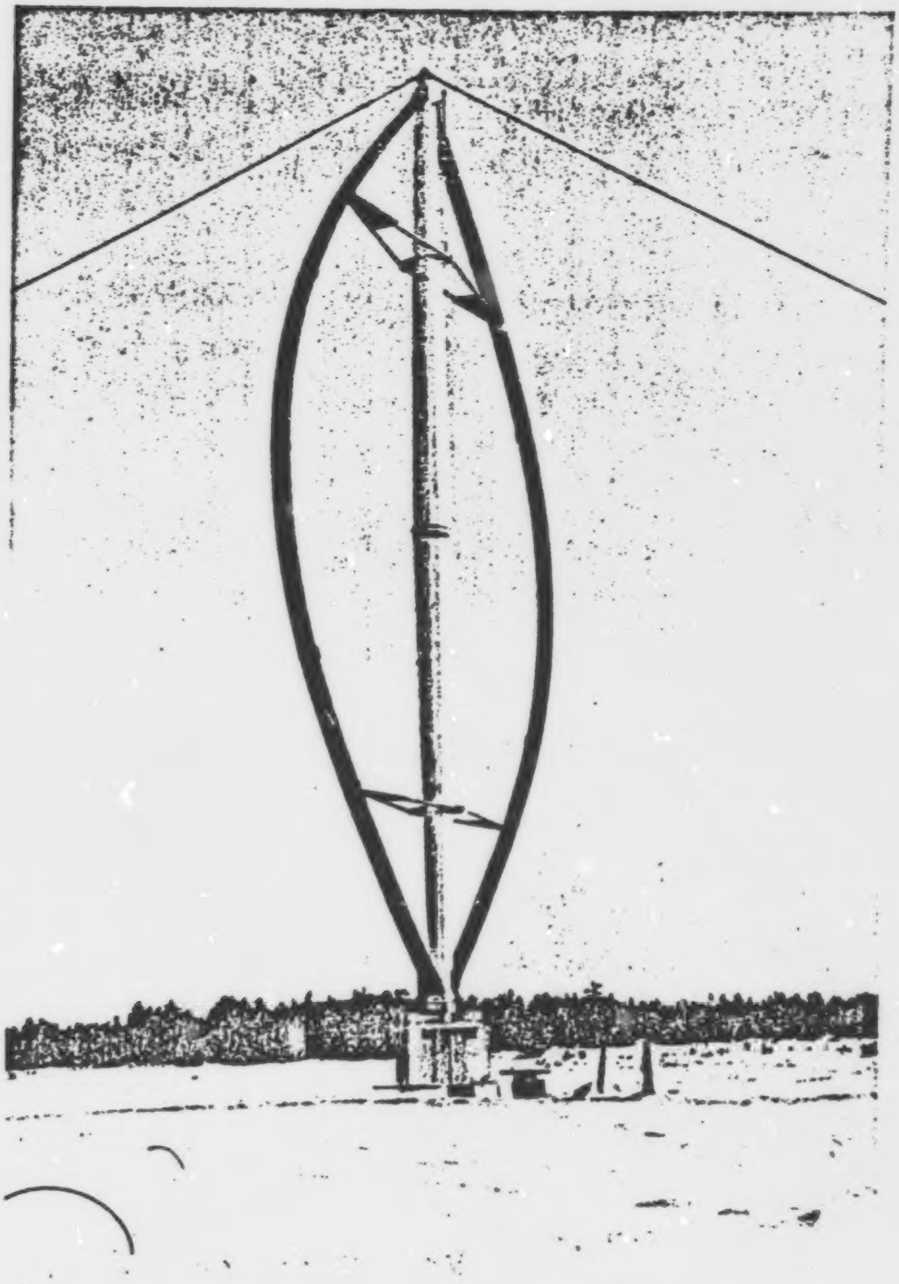


Figure 3. 500 kW prototype VAWT, Atlantic Wind Test Site

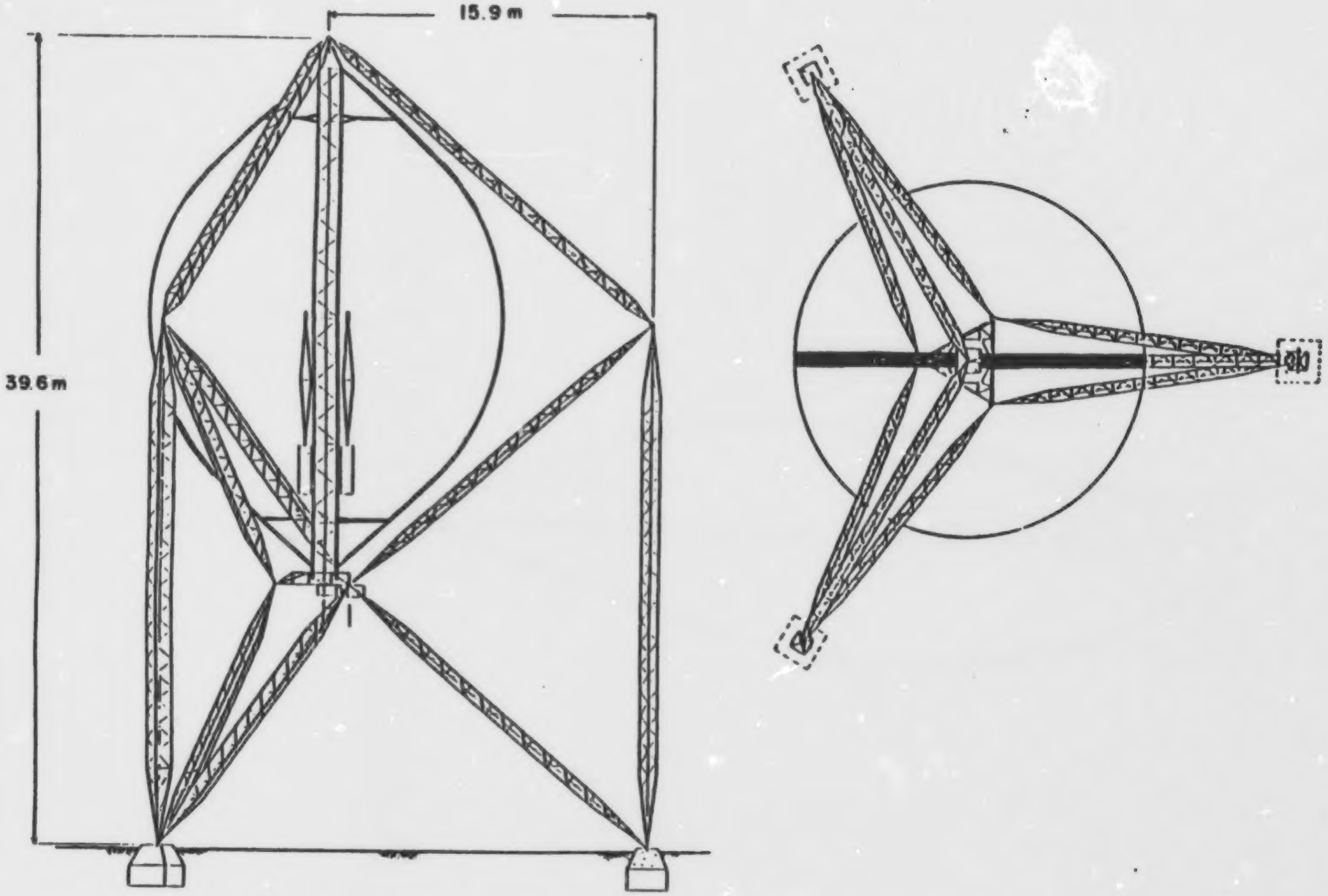
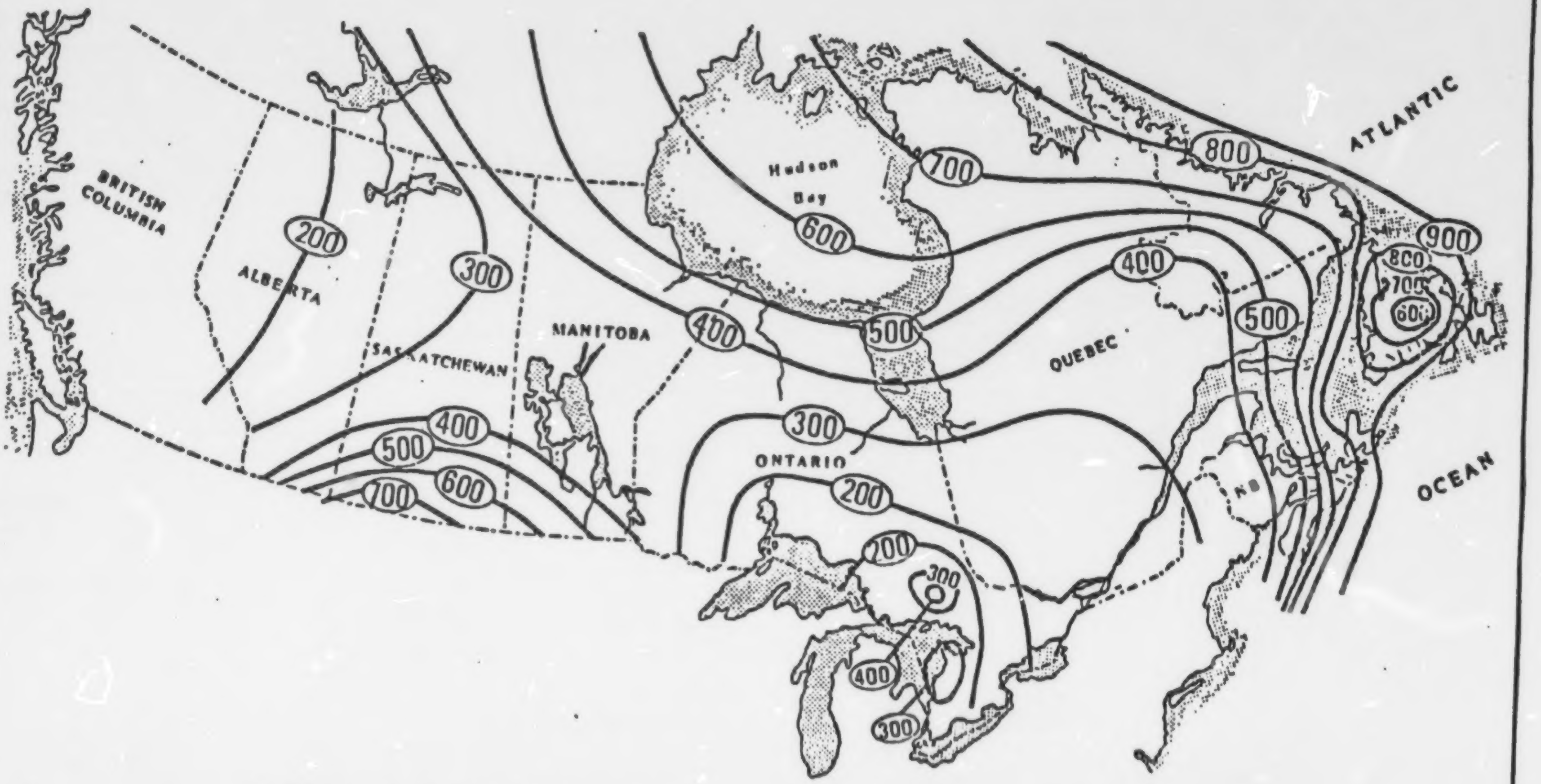
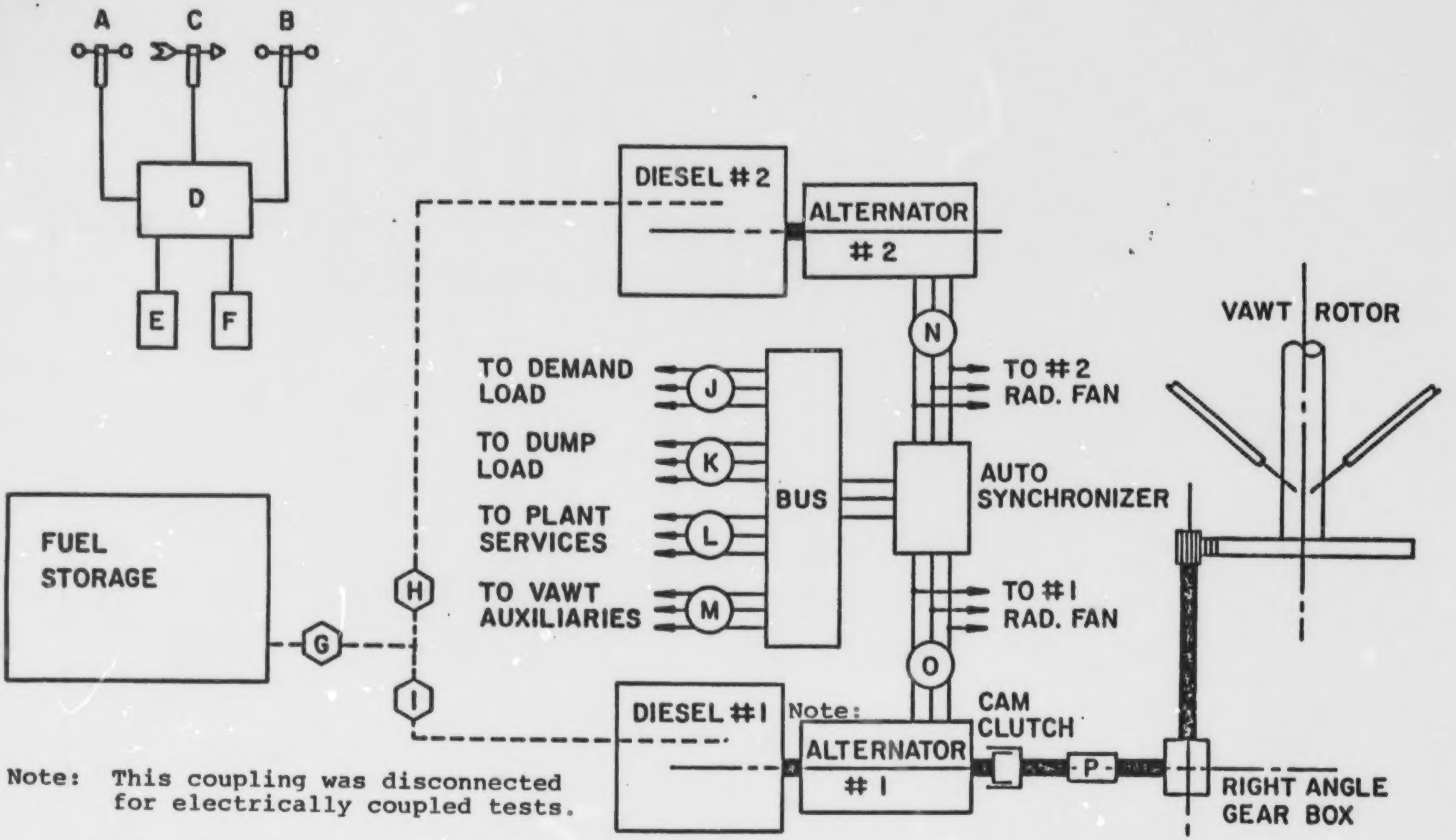


Figure 4. 125 kW experimental VAWT with external support frame


BRITISH COLUMBIA
ALBERTA
SASKATCHEWAN
MANITOBA
Hudson Bay
ONTARIO
QUEBEC
NB
ATLANTIC
OCEAN
200
300
400
500
600
700
800
900
400
500
600
700
300
200
200
300
400
300
800
700
600

ANNUAL AVERAGE WIND ENERGY DENSITY AT 50m ALTITUDE
WATTS/SQ. METRE

Figure. 5


A
C
B
D
E
F
FUEL STORAGE
G
H
I
DIESEL #2
ALTERNATOR #2
DIESEL #1
ALTERNATOR #1
Note:
N
O
J
K
L
M
TO DEMAND LOAD
TO DUMP LOAD
TO PLANT SERVICES
TO VAWT AUXILIARIES
BUS
AUTO SYNCHRONIZER
TO #2 RAD. FAN
TO #1 RAD. FAN
CAM CLUTCH
P
RIGHT ANGLE GEAR BOX
VAWT ROTOR

Note: This coupling was disconnected for electrically coupled tests.

A	ANEMOMETER 30m SW OF VAWT AXIS, AT EQUATOR HEIGHT	I	DIESEL #1 FUEL METER
B	ANEMOMETER 30m N OF VAWT AXIS, AT EQUATOR HEIGHT	J	DEMAND LOAD kWh METER
C	WIND DIRECTION VANE	K	DUMP LOAD kWh METER
D	ANEMOMETER SELECTOR	L	PLANT SERVICES kWh METER
E	WIND HISTOGRAM RECORDER, RUNNING ALL THE TIME	M	VAWT AUXILIARIES
F	WIND HISTOGRAM RECORDER, RUNNING WHEN VAWT IS GENERATING	N	ALTERNATOR # 2 kWh METER
G	TOTALIZING FUEL METER	O	ALTERNATOR # 1 kWh METER
H	DIESEL # 2 FUEL METER	P	TORQUE AND SPEED TRANSDUCERS

Figure 6. Original Wind/Diesel Arrangement

APPENDIX A

Excerpts from Canadian Standards Association F417
Wind Energy Conversion Systems (WECS)
Performance

For either (or both) 99% and 95% confidence levels, a maximum $t/n^{1/2}$ value could be established (say 0.3---ie. 0.3 std's for the half-interval) below which the MDBR is deemed to be met. This approach will work even when $P=0$ or when the std equals zero or is some non-zero value.

Even this approach however fails to give a really good picture of the relative magnitudes of P and the absolute magnitude of the confidence interval. For example, in Table A1 the standard deviations of the power measurements for the 5.5, 6.0, 6.5 and 7.0 m/s windspeed bins are very large percentages of the average power in each bin. If a $t/N^{1/2} = 0.3$ limit criteria was used for a 95% level of confidence, the 6.0, 6.5 and 7.0 m/s windspeed bins would have met the MDBR even though the confidence intervals would have represented 193%, 49% and 19% of the average power in each of their respective bins.

This result illustrates in general the difficulty of obtaining good average power estimates at low output power levels.

The difficulty is compounded if poor correlation exists between windspeed and power measurements due to such things as large anemometer-to rotor separation, hysteresis effects around cut-in, torque ripple, etc.

In order to overcome most of these difficulties in establishing an MDBR criteria for CSA F417, I would suggest to the Subcommittee that Section 6.5.2, be modified to read as follows :

6.5.2 MINIMUM DATA BASE REQUIREMENTS

For windspeed bins in which $P > 25\%$ of WECS rated power, the testing shall not be considered complete until the master bin sort satisfies the condition that the standard deviation of the power readings for each 0.5 m/s wind speed bin is less than

(.1) $(P)\, N^{1/2} / t$ for windspeed bins < 15 m/s

(.2) $(P)\, N^{1/2} / t$ for windspeed bins => 15 m/s

where

P = absolute magnitude of the average power output of the WECS in the windspeed bin

N = number of samples in the windspeed bin ($N > 10$)

t = a variable based on the number of samples in the windspeed bin (see Table 1).

For windspeed bins in which P < 25% of WECS rated power, the testing shall not be considered complete until at least 40, 10 minute averages of power are obtained in each windspeed bin affected.

In all other windspeed bins, each bin shall contain a minimum of 10, 10 minute WECS power averages.

Note: The above requirements control the data such that there is a probability of 0.99 that the true mean is within 10% of the sample mean (P) for windspeeds less than 15 m/s and 20% of the sample mean for windspeed bins equal to or greater than 15 m/s.

For windspeed bins in which P < 25% of WECS rated power, the data is controlled such that the true mean of the bin is contained within a confidence interval of 1 standard deviation of the sample mean with a probability of 0.99.

6.5.2.1

It is strongly recommended that appropriate steps be taken to minimize the standard deviation of the performance data (windspeed & power measurements) to reduce the number of bin entries required to meet minimum data base requirements.
For example, standard deviation of the measurements may be reduced significantly by using the recommended minimum anemometer-to-rotor separation (1.5 rotor diameters) whenever possible.

6.5.2.2

In the event that testing is terminated prior to all bins meeting minimum data base requirements, the Performance Report (Table 2) shall indicate as shown, the status of each windspeed bin with respect to the achievement or non-achievement of minimum data base requirements.

Table 1

Values of $\hat{t}$

Number of samples in wind speed bin	$\hat{t}$ (test constant)
10	3.250
11	3.169
12	3.106
13	3.055
14	3.012
15	2.977
16	2.947
17	2.921
18	2.898
19	2.878
20	2.861
21	2.845
22	2.831
23	2.819
24	2.807
25	2.797
26	2.787
27	2.779
28	2.771
29	2.763
30	2.756
40	2.709
60	2.662
120	2.618

6.5.3 Air Density Measurements and Performance Data Normalization

6.5.3.1 Requirements

For each separate test period the following air density measurements shall be made:

(a) for the case of fixed geometry, constant speed, grid-coupled WECS, the average power level for each bin may be corrected to reflect operation under standard conditions (sea level and 15°C (59°F).

(b) for any other WECS configuration or mode of operation, no air density corrections shall be applied to power measurement.

6.5.3.2 Adjustment to Standard Conditions

6.5.3.2.1 Corrections to Power Measurements for Air Density Variations

For case (a) of 6.5.3.1, the testing facility has the option

(ie. in Kw/hrs, for aerogenerators in kilojoules, for direct heating; in litres/yr x head, for water pumpers)

$$AEO = \left(\frac{3760}{\bar{V}}\right) \sum_{i=1}^{n} f(V_i)P(V_i)\,\Delta V_i$$

Where

V_i = mean of wind speed in bin i

P_i = mean of power reading in bin i

ΔV_i = wind velocity bin width, in bin i.

6.5.5.4 AEO Presentation

As a minimum, the estimated AEO is to be calculated for average annual wind speeds of 4.5, 5.5, and 6.5 m/s (10.0, 12.3, and 14.5 MPH). Where space allows it is recommended that a graph of Estimated AEO versus average wind speed be given. In this case, the range of average wind speeds should be at least 3 to 8 m/s (6.7 - 17.9 MPH). Further details may be found in Clause 8.3.

6.6 Water-Pumping WECS

6.6.1

A system designed specifically for pumping water must be tested in a manner that is consistent with actual field operation. The configuration of the pumping system shall be explicitly stated.

Note: It is recommended that performance tests be carried out for three pumping heads (ie. the rotor with the appropriate pump or pumps should be tested at the proposed minimum, maximum, and typical heads). It should also be stated if heads are partially suction heads.

6.6.2

The test circuit should be designed so that the combined head (static and dynamic) does not vary by more than 5% over the measured flow rates (reference ASTM D3858, Test Method for flow rates).

6.6.3

The water flow rate should be done with the most accurate form of measuring device for the flows; turbine meters are recommended or weirs constructed to approved engineering practices.

6.6.4

If the water load is being adjusted (varying water volume per revolution) a shorter averaging time (not less than one (1) minute) may be used to show the response of the load varying device to changes in wind speed.

6.6.5

When reporting the results of a water-pumping performance test, the head at which the unit was tested must be clearly stated on all graphs or tables. If the head (static and dynamic) has varied by more than 5% over the test, the extreme values must also be included. The test shall state the nature of liquids pumped (ie, fresh or salt water) in the performance test.

6.7 Battery-Charging WECS Performance Measurements

6.7.1 Objectives

(1) To produce a performance curve for two loads conditions and for windspeeds the "cut-in" and "cut-out" windspeed of the WECS, as specified by the manufacturer.

(2) To measure the "effective" maximum and minimum load resistance of battery bank and a specified resistive load for 2 ranges of battery bank terminal voltage:

(a) $E_{FC} - E_{NOM}$

(b) $E_{NOM} - E_{FD}$

where

E_{NOM} = "nominal" battery bank terminal voltage

E_{FC} = "max allowable" battery bank terminal voltage

E_{FD} = "min allowable" battery bank terminal voltage (see Figure 1)

6.7.2 Test Procedure (Refer to Figure 4)

A WECS designed specifically for battery charging shall be tested in a manner that is consistent with actual field operation.

The resistance load(s) to be used in the test should be selected on the basis of manufacturer recommended loads to achieve optimum WECS energy capture for the windspeed distribution expected at the test site during the anticipated test period.

The WECS manufacturer should supply specifications on the battery bank which should include:

(1) "nominal" battery bank terminal voltage;

(2) maximum anticipated battery bank terminal voltage;

(3) minimum anticipated battery bank terminal voltage.

6.7.3 Test Set-Up (see Figure 4)

The test procedure proceeds as follows:

(1) With S_2 closed and S_1 opened, the battery bank is discharged to E_{FD}.

(2) With S_2 open and S_1 closed, the WECS is allowed to charge the battery bank until E_{NOM} is reached. During this time, power P the voltage V and current I are monitored along with windspeed and the Method of Bins applied to the collected data to produce a performance curve. The performance test is terminated each time E_{NOM} is reached at which time S_1 is opened and S_2 closed to discharge to E_{FD}. This is repeated as many times as necessary to obtain a performance curve over the cperating windspeed range of the WECS.

(3) With S_1 closed and S_2 open (after discharging the battery bank to E_{NOM}, the WECS is allowed to charge the battery bank until E_{FC} is reached as many times as necessary until a second performance curve is obtained as in step 2 above.

(4) Current meter I monitors total load current during all test runs. In this way the average current delivered for

terminal voltage conditions of E_{NOM}, E_{FC} and E_{FD} is known and allows calculation of the effective maximum, nominal and minimum load resistances applied to the WECS.

8.7.4

The two performance curves obtained under the above load conditions should be plotted on one graph with clear indication of the maximum, nominal and minimum load resistances calculated as follows:

$R_{FC} = E_{FC}/I_{EC}$ --load resistance at E_{FC}

$R_{NOM} = E_{NOM}/I_{NOM}$ --load resistance at E_{NOM}

$R_{FD} = E_{FD}/I_{FD}$ --load resistance at E_{FD}

Note: If the WECS load controller disconnects the load when $V = E_{FC}$ or $V = E_{FD}$ then $I_{FC} = I$ or $I_{FD} = I$ just prior to automatic disconnect.

INITIAL DATA FROM A SURVEY OF WIND TURBINES INSTALLED IN CANADA

By

David Hoffman

World Wind Communications Co.
44A Clarey Avenue,
Ottawa, Ontario K1S 2R7,
Canada.

Presented

at the

Canadian Wind Energy Conference 1986

Quebec City, Quebec, Canada
October 1986

ABSTRACT

A survey of all wind turbines erected in Canada since 1970 is being conducted. The survey will document the number, type, generating capacity and operational history of each wind turbine. Data from the survey is expected to be useful to the wind power industry in the areas of marketing and field service. The data is expected to be useful to the wind turbine owners in the areas of awareness of other owners and improving system reliability and performance.

SUMMARY

A national survey of wind turbines has never before been conducted in Canada and nor have regional surveys been published.

The survey is in progress. A literature search has revealed a total number of 185 wind turbines installed in Canada since 1970, with generating capacity totalling 663 kilowatts. Wind turbines built for the National Research Council or installed at the Atlantic Wind Test Site are not included in the survey.

The literature search has identified individual wind turbines. Each wind turbine owner will receive a survey questionaire that will ask for details outlined in the abstract of this paper. Follow-up telephone calls will be made when necessary to complete the survey. Wind turbine manufacturers and suppliers will be asked to volunteer a list of wind turbine owners. However, it is estimated that most of the actual total number of wind systems in Canada have already been identified in the literature search.

Once the survey has been completed, the information will be compiled in a database and analyzed. The analysis will examine the trends in:

--annual installations broken down by province, system application and generating capacity.

--system reliability and performance as observed by the owner and supplier support where it is applicable.

--related factors such as weather severity and electric utility involvement where grid-connected windplants are involved.

A final report will be published containing the raw data, the analysis of trends, conclusions about the trends and some recommendations for later activity.

As the project is still in progress and data is still being accumulated, findings can not yet be published. The total of 185 wind turbines identified in the literature survey is expected to increase in number before the project has been completed as more existing installations are identified and new installations are completed up to the end of 1986.

As a preliminary illustration of the data to be compiled, three tables are provided. The data in each is broken down by year and province. Table 1 contains the total number of wind turbine installations. Table 2 contains the corresponding generating capacity added each year. Table 3 provides a breakdown of installations of wind generators built by one manufacturer, the Dunlite company of Australia.

ACKNOWLEDGEMENTS

The project is funded by the federal Department of Energy, Mines and Resources. The author wishes to acknowledge his gratitude to the Department's renewable energy branch for their support.

TABLE 1 NUMBER OF WIND TURBINES ERECTED IN CANADA
BY PROVINCE AND YEAR (Does not include turbines for which installation date is not yet known)

PROVINCE	YEAR										TOTAL
	1970- 1975	1976- 1978	1979	80	81	82	83	84	85	86	
ALTA.	0	1	0	1	2	0	1	3	5	3	16
B.C.	7	10	11	13	4	0	2	1	0	0	48
MAN.	0	0	0	0	0	0	7	0	0	0	7
N.B.	0	0	0	0	1	0	4	1	0	0	6
NFLD.	0	0	0	0	0	0	2	0	0	0	2
N.W.T.	0	0	0	0	0	2	0	0	1	0	3
N.S.	0	0	0	9	16	8	5	0	0	0	38
ONT.	1	6	1	7	5	5	3	2	3	2	35
P.E.I.	0	0	1	1	0	1	0	0	1	0	4
QUEBEC	0	1	0	0	2	2	0	2	1	1	9
SASK.	0	0	0	1	1	0	2	0	0	0	4
YUKON	0	0	0	0	0	0	0	1	0	0	1
TOTAL	8	18	13	32	31	18	26	10	11	6	183

TABLE 2 CAPACITY OF WIND TURBINES ERECTED IN CANADA
BY PROVINCE AND YEAR IN KILOWATTS (Does not include

turbines for which capacity and installation date is not yet known)

PROVINCE	1970 -75	1976 -78	1979	80	81	82	83	84	85	86	TOTAL
ALTA.	0.0	1.5	0.0	2.0	7.0	0.0	1.8	15.0	25.6	185	237.9
B.C.	13.0	18.6	3.8	27.2	1.5	0.0	4.0	5.0	0.0	0	73.1
MAN.	0.0	0.0	0.0	0.0	0.0	0.0	25.0	0.0	0.0	0	25.0
N.B.	0.0	2.0	0.0	0.0	2.0	0.0	13.3	24.0	0.0	0	41.3
NFLD.	0.0	0.0	0.0	0.0	0.0	3.8	2.2	0.0	0.0	0	6.0
N.W.T.	0.0	0.0	0.0	0.0	0.0	3.0	17.5	0.0	4.0	0	24.5
N.S.	0.0	0.0	0.0	7.9	16.8	13.0	11.0	0.0	0.0	0	48.7
ONT.	2.0	8.7	2.2	2.0	0.0	0.2	10.8	1.8	0.2	0	27.9
P.E.I.	0.0	0.0	0.0	0.5	0.0	1.0	0.0	0.0	40.0	0	41.5
QUEBEC	0.0	4.0	0.0	0.0	0.3	11.0	0.0	6.0	25.0	65	111.3
SASK.	0.0	0.0	0.0	15.0	0.0	0.0	11.0	0.0	0.0	0	26.0
YUKON	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.0	0	0.2
TOTAL	15.0	34.8	6.0	54.6	27.6	32.0	46.6	52.0	94.8	250	663.6

TABLE 3 TOTAL NUMBER OF DUNLITE WIND GENERATORS ERECTED IN CANADA BY PROVINCE AND YEAR

PROVINCE	1970-1975	1976-1978	1979	80	81	82	83	84	85	86	TOTAL
ALTA.	0	0	0	0	1	0	0	0	0	0	1
B.C.	7	6	2	12	0	0	2	1	0	0	30
MAN.	0	0	0	0	0	0	0	0	0	0	0
N.B.	0	1	0	0	1	0	0	0	0	0	2
NFLD.	0	0	0	0	0	0	0	0	0	0	0
N.W.T.	0	0	0	0	0	0	0	0	0	0	0
N.S.	0	0	0	2	3	1	0	0	0	0	6
ONT.	1	0	0	1	0	0	0	0	0	0	2
P.E.I.	0	0	0	0	0	0	0	0	0	0	0
QUEBEC	0	0	0	0	0	0	0	0	0	0	0
SASK.	0	0	0	0	0	0	1	0	0	0	1
YUKON	0	0	0	0	0	0	0	0	0	0	0
TOTAL	8	7	2	15	1	2	1	0	0	0	41

REFERENCES:

File CONF. disc CONTRACT DISC 1 (COP 2).

MS-Micro : A MICROCOMPUTER VERSION OF A THREE-DIMENSIONAL WIND FLOW MODEL FOR USE IN COMPLEX TERRAIN

J.R. Salmon
24 Heslop Drive
Toronto, Ontario
M8W 4R1

R.J. Morris
Atmospheric Environment Service
Environment Canada
4905 Dufferin Street
Downsview, Ontario M3H 5T4

1. INTRODUCTION

MS-MICRO is a microcomputer implementation of the MS3DJH/3R numerical model for computing wind flow over complex terrain. The original model code was developed on a CRAY-1S computer mainly by Dr. J.L. Walmsley of the Boundary Layer Research Division of the Atmospheric Research Directorate of the Atmospheric Environment Service of Canada and is available in a transportable version for mainframe computers from Dr. Walmsley. The version to be described here is a direct descendent of the mainframe model although it has been modified substantially to operate efficiently in the microcomputer environment. Also, several routines for pre-processing model input data and post-processing model output have been written or re-written to make this version function in a unified suite of programs from digitization of topographic contours and roughness boundaries through to plotting of normalized wind speed contour maps. The advantage of this microcomputer version is that the whole process can be carried through by a single operator at a work station no larger than a typical table top. The main disadvantage is that the model calculations are considerably slower than those done with the CRAY-1S computer.

The following sections contain descriptions of theoretical and numerical modelling background material, the hardware required for the system, the software and finally, sample contour plots of system output are presented.

2. BACKGROUND

The original MS3DJH program arose from a desire to accurately and efficiently predict modifications to the boundary layer wind field caused by local topography. The theory of Jackson and Hunt (1975) as expanded to three dimensions by Mason and Sykes (1979) proved to be an ideal starting point for the MS3DJH series of numerical models. Walmsley et al. (1982) applied the theory (heretofore confined to simple analytic terrain features) to real terrain in the first of the MS3DJH models and encountered reasonable success in matching predictions with field and wind-tunnel data. Since that time the numerical model has undergone a number of changes up to the present MS3DJH/3R model which incorporates wavenumber-dependent scaling, efficient Bessel function table look-ups and wind speed modifications due to surface roughness variations. It is this latest version of the model on which MS-Micro is based. With MS3DJH/3R, a high resolution three-dimensional prediction using 256 by 256 grid points in the horizontal to define topography and aerodynamic roughness can be achieved in a small fraction of the time required by finite difference or finite element techniques.

Briefly, the model is based on a division of an assumed neutrally-stratified flow field into inner and outer layers. The outer layer is characterized by inviscid, potential flow while, in the inner layer, a balance between advective, pressure-gradient and turbulent-viscous forces is assumed and turbulent transfers are modelled with a simple mixing length closure scheme. Scale considerations and use of a terrain-following vertical coordinate permit linearization of the equations for a range of parameters. Fourier transforms of the linearized equations result in Bessel equations in the Fourier coefficients. The transformed equations are ordinary differential equations in the vertical coordinate. They can be solved analytically with an inverse transform providing the desired velocity modifications. Neutral stratification and scale considerations, linearization and use of the Finite Fourier Transform impose limitations on the circumstances under which the model will provide valid solutions. These follow:

1.) The boundary layer is assumed to be neutrally stable. This is usually the case during moderate and high wind situations when mechanical mixing of the air is the dominant process.

2.) The terrain slopes are less than about one in four. This precludes steep or mountainous terrain where flow separation can occur.

3.) The terrain being modelled is not so extensive that synoptic variability must be considered. The model assumes a homogeneous, well-developed incident wind profile. It also assumes that Coriolis effects are negligible.

4.) The prediction levels are not so high that they are above the atmospheric boundary layer nor are they so low that they are near the roughness element height. These two situations would violate the assumptions made in the scaling arguments for linearization of the equations.

(For the preceding two limitations, a general rule of thumb is that the horizontal length scales should be between about 10m and 10km and the vertical solution levels should lie between about 1m and 150m.)

5.) It must be possible to represent the region as an area of complex topography and aerodynamic roughness surrounded by a flat, homogeneous plain. This constraint is not so stringent as it may at first appear. The terrain and roughness pre-processors for the model input can "massage" nearly any terrain into a suitable configuration when a large enough domain is selected.

(It should be noted here that work is in progress in the AES Boundary Layer Research Division to remove some of the above restrictions thereby making the model more generally applicable.)

The restrictions listed above need to be considered seriously when using MS-Micro for deriving wind field modifications. If they are ignored, the results will be at best inaccurate and possibly entirely wrong. The best way to prevent erroneous predictions is to become familiar with the material in the references which, incidentally, have been supplemented to include all of the essential material detailing the development of the MS3DJH series of models.

3. HARDWARE

The hardware used for development and necessary for full implementation of MS-Micro is shown schematically in Figure 1. The heart of the system is an IBM PC/AT microcomputer (including keyboard and an Amdek 310 monochrome monitor) running under the MS-DOS operating system. It features 640 kbytes of main memory, a 20 Mbyte fixed disk drive and an 80287 numeric coprocessor. The microcomputer accepts graphical input from a Calcomp model 2000 digitizer, performs all pre-processor, model and post-processor calculations and sends output to a Toshiba model P1350 printer and a Hewlett-Packard model 7470A plotter. As stated previously, all of this hardware will fit on a single table top.

4. SOFTWARE

A brief description of the steps that a user follows to compute the wind field in complex terrain is probably the easiest way to introduce MS-Micro.

Before starting the analysis, the user has obtained a topographic map and a roughness (usually land-use) map of the region under study. These are the primary inputs into the system. He/she has marked an origin and a horizontal (i.e. parallel to the E-W direction) scale bar on both maps and has decided what portion of the region should be taken as the computational domain. He/she also has decided which incident wind directions (since wind speed modifications will depend on the incident wind direction) are to be examined and at which vertical levels (above the local terrain) he/she desires output wind fields.

Using the digitizer and program MSTCON the user creates a file containing the coordinates of the contour lines and their elevations. A second file containing information on the boundaries between areas of differing aerodynamic roughness and information on "seed points" which are used to define the roughness within each individual roughness area is created with the digitizer and program MSRCON.

Next, a file named MSMASTER.PAR must be created using program MSPAR. This file contains all of the information required by the system to compute the wind fields as modified by the complex terrain - except, of course, the topographic and roughness information contained in the two files described above. Program MSPAR functions as a question and answer session with default answers available from the previous run of the system. Questions which must be answered relate to the number of grid lines (x and y; grids can range from 16x16 to 256x256) used to set up the computational grid on which the topography, roughness and normalized wind speeds are defined, the limits (north, south, east and west) of the computational domain, the incident wind directions to be considered, the mean elevation in the direction of each incident wind, the average climatological wind speed and frequency of occurrence in each incident wind direction, the names of the topography and roughness files, data origin shifts (if desired), two topography massaging parameters (to be explained later) and the number and values of the vertical levels at which the modified wind field is to be computed. The program prints a reference summary of these input parameters containing a unique, time-stamped, user-defined header which will appear on all subsequent output for ready identification.

The next step is to invoke program MSTG to create a grid of elevations over the computational domain for each specified incident wind and store these grids in separate files. A separate grid is created for each direction because the numerical model, MS3DJH/3R, assumes that the incident wind is parallel to the x-axis and from the negative sense. Therefore, to consider any incident wind direction except due west, the topographic (and roughness) grid must be rotated so that the incident wind direction is aligned with the negative x-axis.

Program MSTG fits tensioned cubic splines through the contour levels along orthogonal grid lines to create an accurate gridded representation of the topography. This grid is then massaged in such a way that the accurate representation is retained in the centre of the grid while a flat, zero-level plain is generated in the exterior of the computational domain. The interior and exterior topographies are smoothly "blended" into each other in the intervening region.

Program MSRG, which can be run before or after program MSTG, is used to generate the appropriate number of aerodynamic roughness grids. These grids are created in a way very different from that used for the topography grids. The grid points in each area defined by the roughness boundaries digitized in program MSRCON are "filled" from the digitized "seed point" whose value was assigned during the digitization process.

Once the topographic and roughness grids have been created, program MS3R (which is the MS3DJH/3R model) is run to generate the normalized wind speed fields for each incident wind direction and vertical level specified. The output consists of subset grids of the generated fields (which have been re-oriented back to the original NESW direction) displayed on the console or sent to the printer and output files containing the gridded normalized wind speeds. The normalization factor is the unperturbed wind speed at the vertical elevation (above the upstream flat topography) specified for the solution. (Note that the vertical coordinate system is terrain-following so that a ten meter solution level is ten meters above the topography everywhere.)

Perhaps, the most useful output is generated by program MSCP which drives the plotter to produce contour maps of the normalized wind speed fields (one for each direction and level) as well as a contour map of the (massaged) topographic data and a boundary map of the aerodynamic roughness areas. The program will also combine the individual normalized wind speed fields and the data on wind speed and frequency from each specified direction to produce a direction/frequency-averaged, composite, normalized wind speed contour map for the domain.

When this sequence of events is completed, the user can examine the output (mainly the contour maps of normalized wind speed) and determine whether further computation is required. If so, it is a simple matter to rerun program MSPAR, change one or more parameters (all others will default to their previous values) and run through the system from that point on again.

The software for the MS-Micro system consists of three programs written in BetterBasic and five programs written in MS-Fortran (MicroSoft Fortran). A system flow chart showing these programs is displayed in Figure 2. Normally, the user would run these programs one-by-one in the sequence shown from top to bottom in the figure. The programs exchange data via files on the hard-disk. These are also shown in the figure.

5. AN EXAMPLE OF AN MS-Micro RUN

In this section, output from a typical analysis by the MS-Micro system is presented in the form of contour maps generated by program MSCP.

Figures 3 and 4 are topographic and roughness maps describing the complex terrain (in this case a portion of Sable Island, Nova Scotia) for which normalized wind speed fields have been calculated. Note that Figure 3 is actually a contour map of the massaged, gridded terrain (and not the original contour map). We wished to determine the normalized wind speeds for incident wind directions of 197 and 8 degrees at an above-the-ground elevation of 10m. It was decided to perform the computations at the highest resolution available (256x256 grid lines) on a 5120mx5120m computational grid centred about the origin. At this maximum resolution the model calculations required about 1.6hr for each level and incident wind direction on the IBM/AT microcomputer. (We believe that this time can be reduced significantly (<30min) using newer microcomputers with much higher clock rates.)

Figure 5 displays the normalized wind speed at 10m over the central quarter of the computational domain for an incident wind direction of 197 degrees while Figure 6 pertains to an incident wind direction of 8 degrees. These predictions have been compared with field measurements of the normalized wind speed along a line across the island. The results are reported in Walmsley and Salmon (1986).

Figures 5 and 6 suggest an obvious use for the MS-Micro system and that is in choosing the optimal site (in terms of terrain-induced augmentation of the wind) for a Wind Energy Conversion System. It is a simple matter to choose the point with maximum normalized wind speed from the contour maps. Furthermore, there is a facility in the system that allows automatic calculation and plotting of a synthesized normalized wind speed contour map based on the climatological behaviour (direction and average speed from that direction) of the incident wind. In this case, the normalized wind speed value at the optimal location is a realistic representation of the increased wind speed averaged over a long period.

6. SUMMARY

A microcomputer-based system, MS-Micro, which calculates terrain-induced wind speed modifications starting from topographic and land-use maps has been described. The system is very easy to use. An operator can digitize the topography and aerodynamic roughness, compute the velocity perturbation fields for any set of incident wind directions and vertical levels with a state-of-the-art, high-resolution, three-dimensional numerical model and produce high-quality contour maps of the normalized wind speed predictions in the course of a working day without ever leaving his chair.

A few examples of uses for the MS-Micro system are WECS site prospecting, local climatology studies, local site surveys for airports and provision of input for local pollutant dispersion studies.

ACKNOWLEDGEMENTS

The authors wish to thank Dr. J.L. Walmsley for making the MS3DJH/3R code (as well as the pre-processor code) so readily available. They also wish to thank Drs. Walmsley and P.A. Taylor for their helpful suggestions and invaluable advice during the course of the project.

The work described in this paper was supported by the Federal Panel on Energy Research and Development (PERD).

References

Jackson,P.S. and Hunt,J.C.R.:1975,'Turbulent Wind Flow Over a Low Hill',Quart.J.R.Meteorol.Soc. 101,833-851.

Mason,P.J. and Sykes,R.I.:1979,'Flow Over an Isolated Hill of Moderate Slope',Quart.J.R.Meteorol.Soc. 105,383-395.

Salmon,J.R. and Walmsley,J.L.:1986,'User's Guide to the MS3DJH/3R Model',Rep.86-I-2,Atmos.Environ.Service,Downsview,Ontario.

Salmon,J.R.,Walmsley,J.L. and Taylor,P.A.:1981,'MS3DJH/2 - Development of a Model of Neutrally Stratified Boundary-Layer Flow Over Real Terrain',Rep.AQRB-81-023-L,Atmos. Environ.Service,Downsview,Ontario.

Taylor,P.A. and Walmsley,J.L.:1981,'Estimates of Wind-Speed Perturbation in Boundary-Layer Flow over Isolated Low Hills - A Challenge',Boundary-Layer Meteorol. 20,253-257.

Taylor,P.A.,Walmsley,J.L. and Salmon,J.R.:1983,'A Simple Model of Neutrally Stratified Boundary-Layer Flow Over Real Terrain Incorporating Wavenumber-Dependent Scaling',Boundary-Layer Meteorol. 26,169-189.

Taylor,P.A.,Walmsley,J.L., and Salmon,J.R.:1985,'Guidelines and Models for Estimating Wind Speeds at WECS sites in Complex Terrain',Proc. Intersol '85,Montreal,Canada,June 1985 (in press).

Walmsley,J.L. and Salmon,J.R.:1986,'A Study of Boundary-Layer Winds on Sable Island, Nova Scotia, Canada: Comparison Between Measured Data and Model Estimates',Proc. EWEC'86, European Wind Energy Association Conference and Exhibition, Rome, Italy, 7-9 October 1986.

Walmsley,J.L. and Taylor,P.A.:1981,'Estimates of Wind-Speed Perturbations in Boundary-Layer Flow Over Isolated Low Hills - Solutions',Boundary-Layer Meteorol. 20,391-395.

Walmsley,J.L.,Salmon,J.R., and Taylor,P.A.:1982,'On the Application of a Model of Boundary-Layer Flow Over Low Hills to Real Terrain',Boundary-Layer Meteorol. 23,17-46.

Walmsley,J.L.,Taylor,P.A., and Keith,T.:1986,'A Simple Model of Neutrally Stratified Boundary-Layer Flow Over Complex Terrain with Surface Roughness Modulations (MS3DJH/3R)', Boundary-Layer Meteorol. 36,157-186.

Walmsley,J.L.,Taylor,P.A. and Mok,R.:1980,'MS3DJH - A Computer Model for the Study of Neutrally Stratified Boundary-Layer Flow Over Isolated Hills of Moderate Slope',Rep.AQRB-80-008-L,Atmos.Environ.Service,Downsview,Ontario.

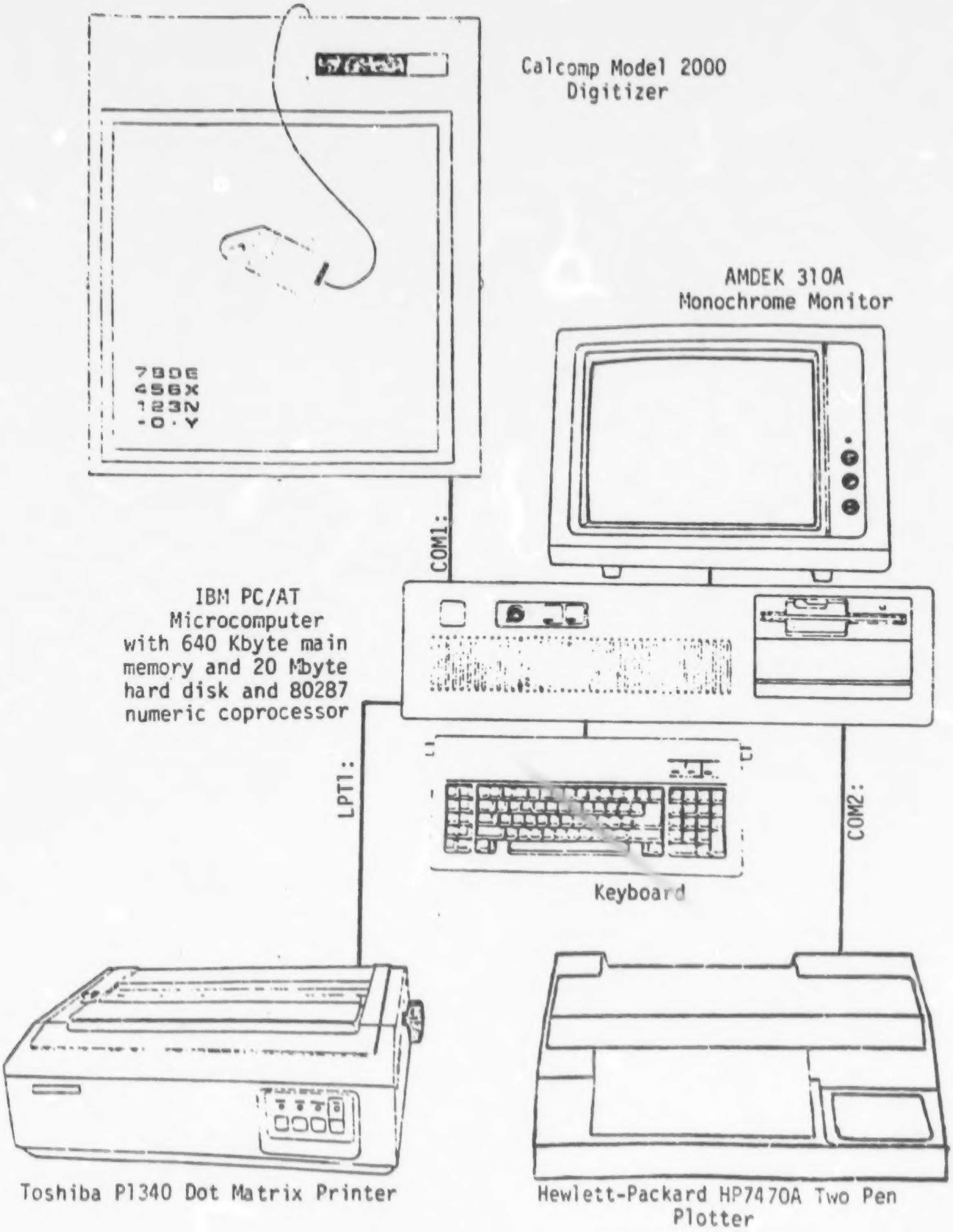

Calcomp Model 2000
Digitizer
7 8 9 E
4 5 6 X
1 2 3 N
- 0 · Y
AMDEK 310A
Monochrome Monitor
COM1:
IBM PC/AT
Microcomputer
with 640 Kbyte main
memory and 20 Mbyte
hard disk and 80287
numeric coprocessor
LPT1:
COM2:
Keyboard
Toshiba P1340 Dot Matrix Printer
Hewlett-Packard HP7470A Two Pen
Plotter

Figure 1. Schematic diagram of the hardware and interconnections for the MS-Micro system.

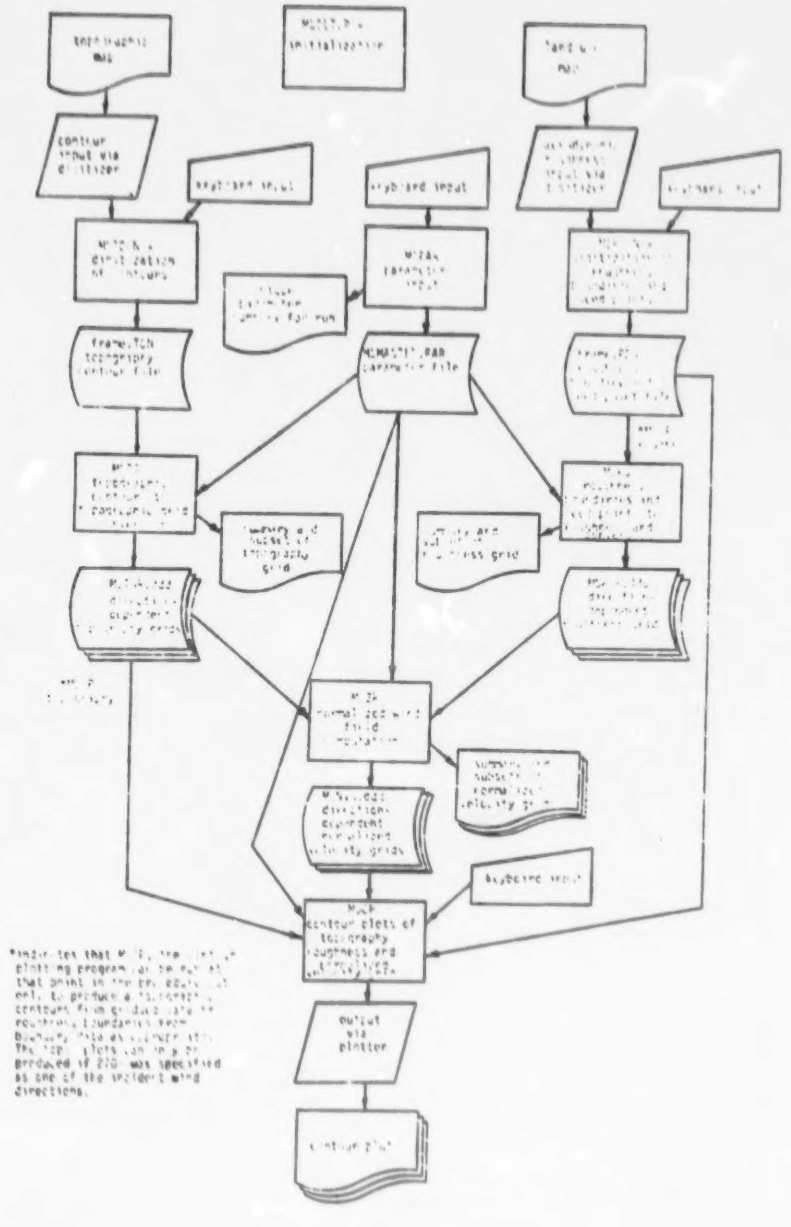

topographic map
initialization
land use map
contour input via digitizer
keyboard input
keyboard input
digitization of contours
parameter input
frame.TCN topography contour file
parameter file
summary and subset of topography grid
roughness grid
normal zed wind field computation
direction-dependent normalized velocity grids
keyboard input
contour plots of topography roughness and
output via plotter
contour plot

Figure 2. System flow chart of the MS-Micro system showing the steps required to generate contour plots of normalized wind speed fields over a complex terrain feature represented by topography and aerodynamic roughness (land-use) maps.

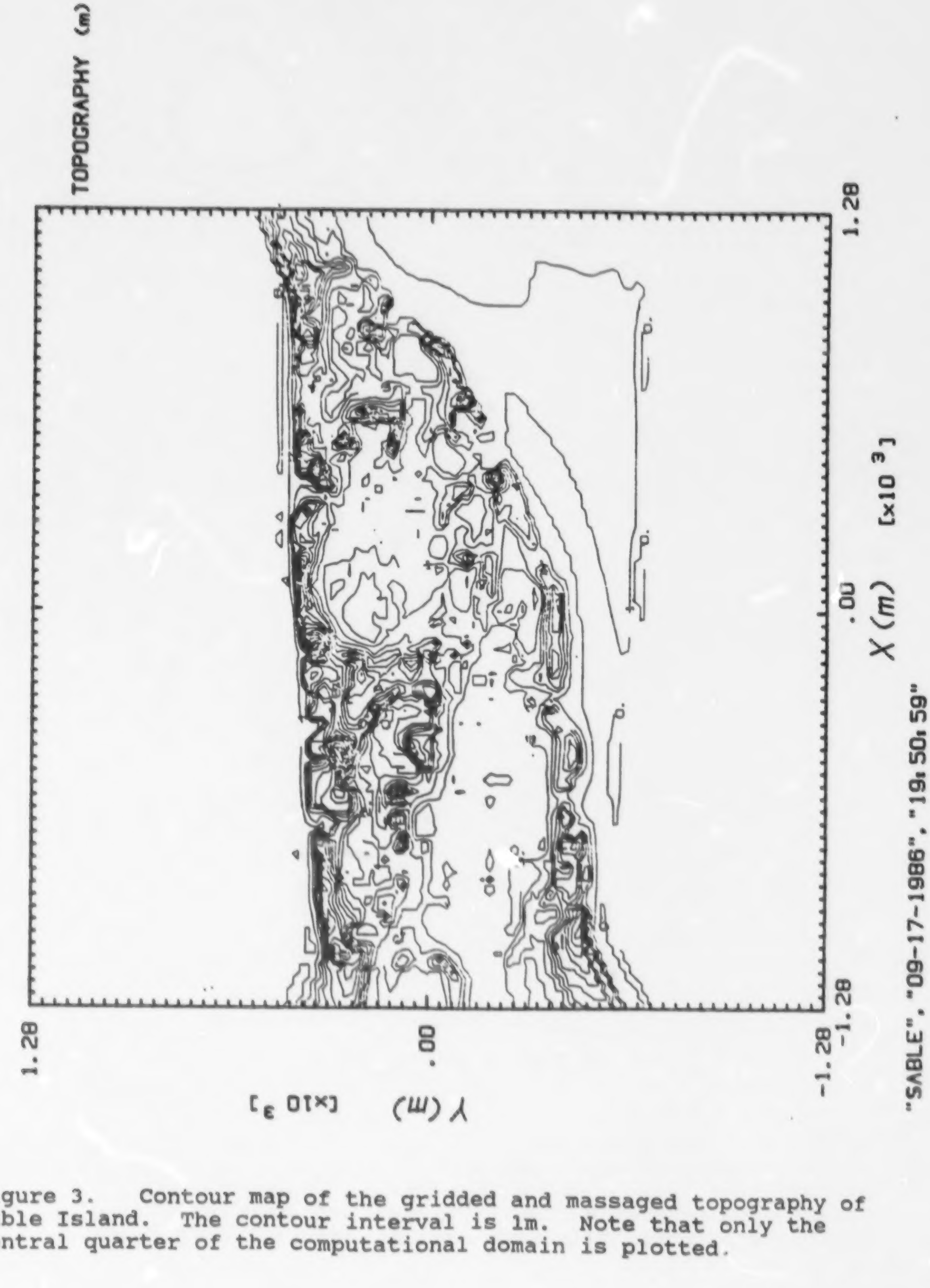

TOPOGRAPHY (m)
1.28
.00
-1.28
X (m) [x10 3]
Y (m) [x10 3]
"SABLE","09-17-1986","19:50:59"

Figure 3. Contour map of the gridded and massaged topography of Sable Island. The contour interval is 1m. Note that only the central quarter of the computational domain is plotted.

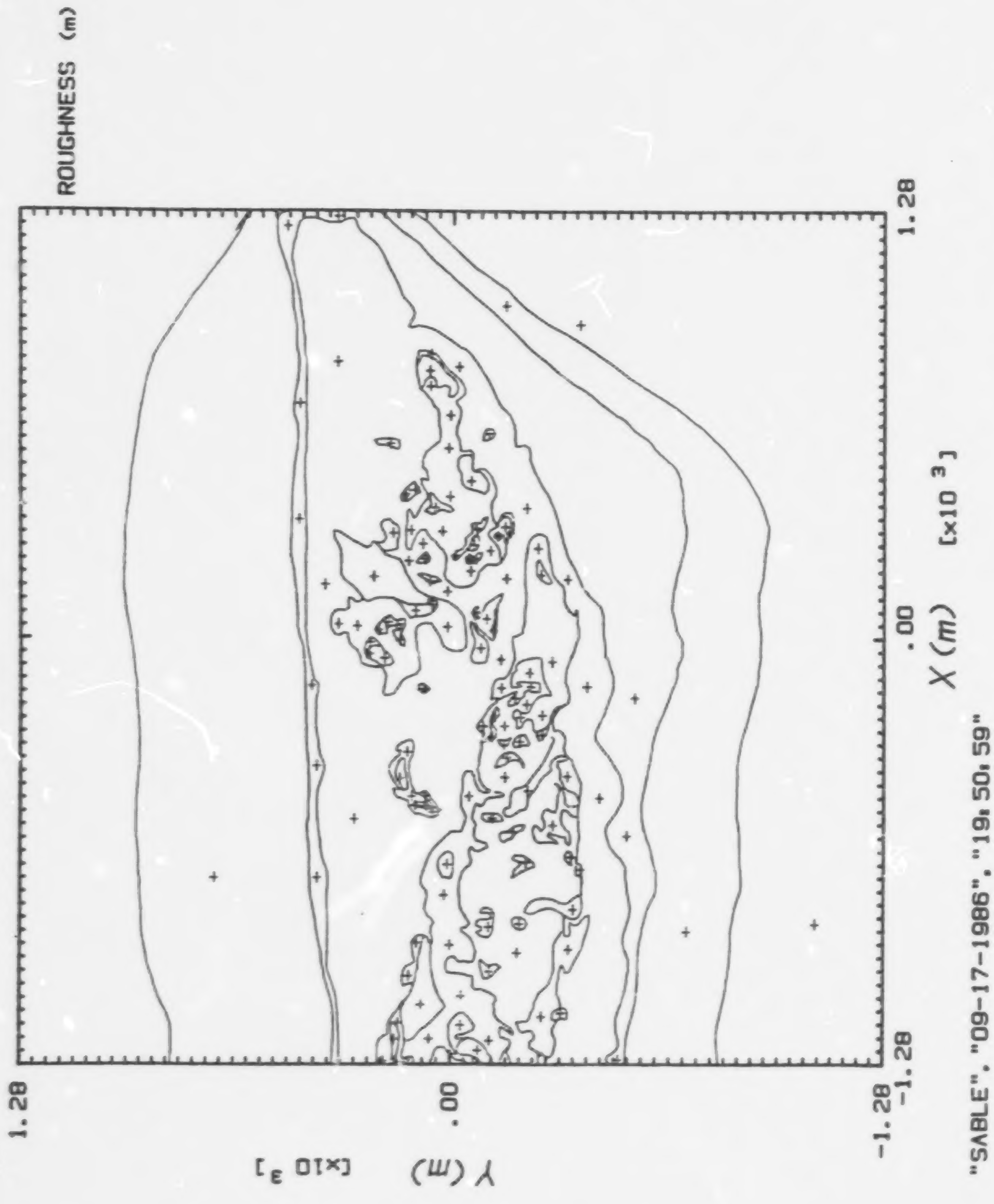


Figure 4. Diagram showing the boundaries separating regions of different aerodynamic roughness. The crosses show the locations of the "seed points" used to assign roughness lengths to the bounded region in which each seed point lies. Note that only the central quarter of the computational domain is plotted.

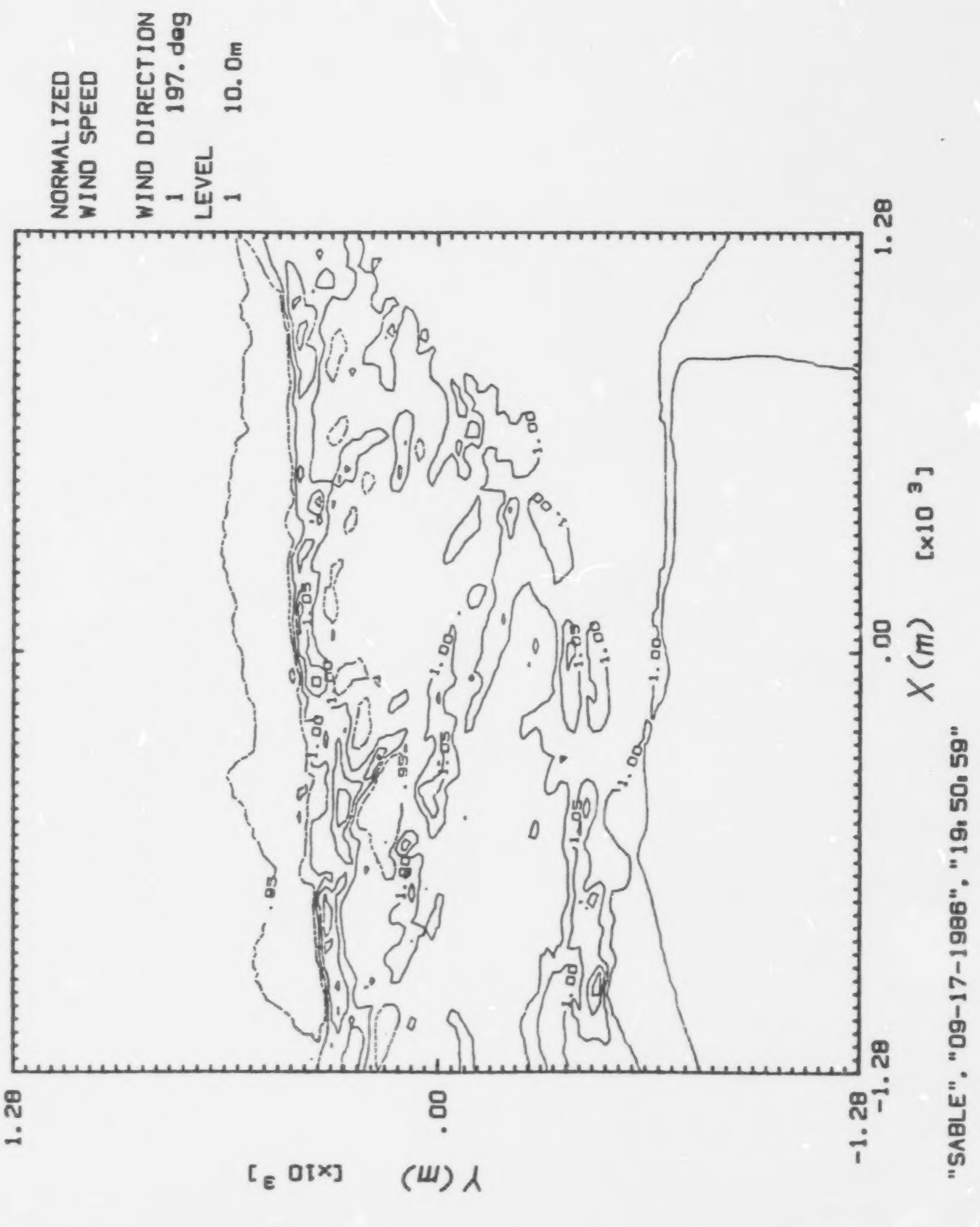


Figure 5. Contours of normalized wind speeds at 10m over Sable Island for an incident wind direction of 197 degrees. The contour interval is 0.05. Note that only the central quarter of the computational domain is plotted.

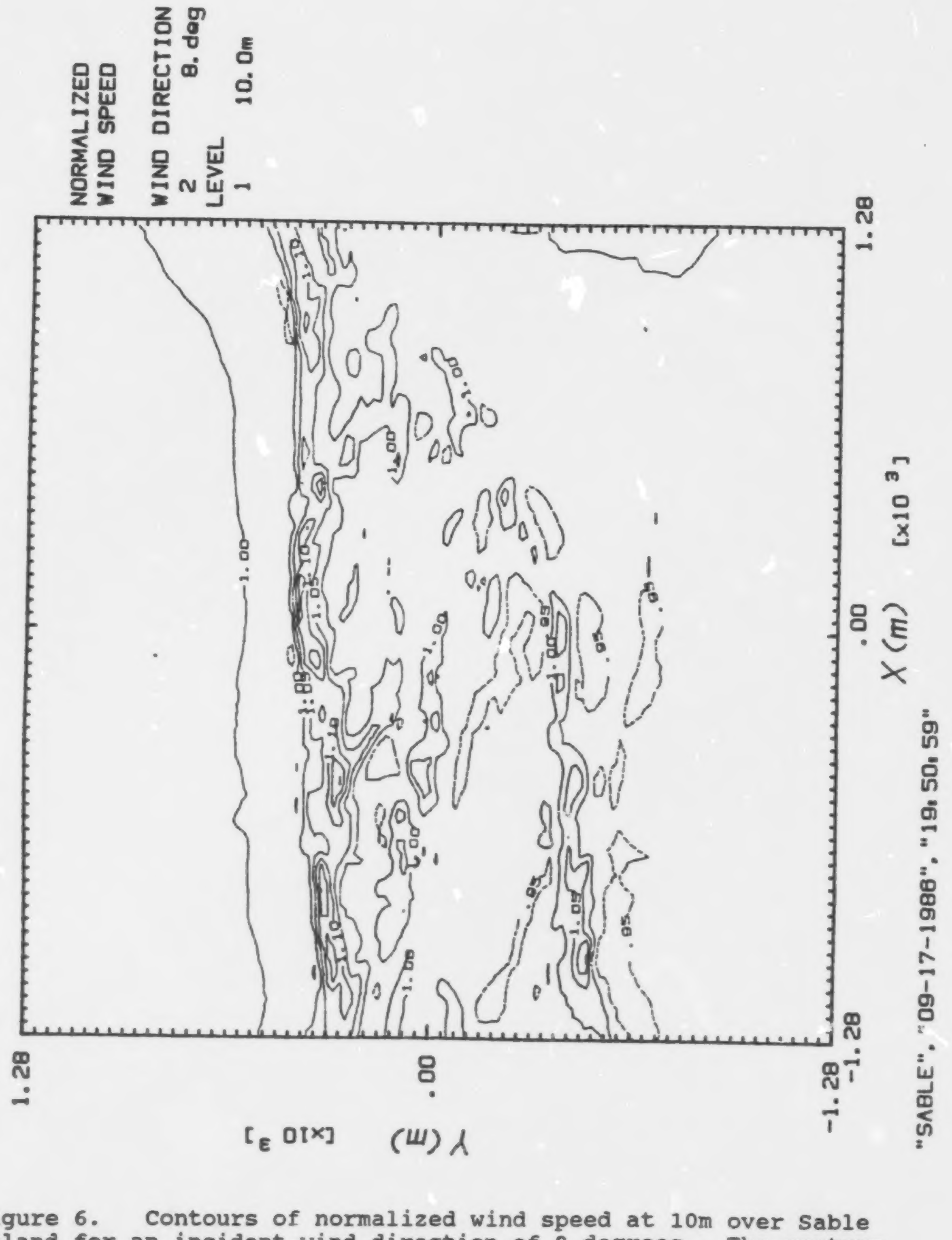


Figure 6. Contours of normalized wind speed at 10m over Sable Island for an incident wind direction of 8 degrees. The contour interval is 0.05. Note that only the central quarter of the computational domain is plotted.

WIND-TUNNEL MODELLING OF ATMOSPHERIC BOUNDARY-LAYER FLOW OVER AN ISOLATED HILL

by

Mohamed Shokr

Atmospheric Environment Service
Toronto, Canada

ABSTRACT

Determining the best site for location of WECS requires accurate information about atmospheric boundary-layer flow over different terrain features. Atmospheric Environment Service (AES), along with six institutes from five different countries, was involved in a wind-energy related experiment designed to examine the effect of hills on wind flow. The site under study was an elliptical, isolated hill, named Askervein, located in Scotland. Wind-tunnel simulation of neutrally-stable atmospheric flow over the hill was carried out at a model scale 1:1200 in the AES boundary-layer wind tunnel. The results provide information about the location and the extent of the steady accelerated flow regions, which constitute areas of preferred WECS sites, and also about high turbulence flow regions which should be avoided as candidate WECS sites. The study also elaborates on the sensitivity of the mean flow and turbulence characteristics to the prevailing wind direction of the mean flow.

Nomenclature

H	maximum height of the hill
L	hill-half-length
h	local height of the hill
$\bar{U}$	mean streamwise velocity
u	instantaneous fluctuating components of the streamwise velocity
T_u	turbulence intensity in the streamwise direction
Z	height above the flat terrain upstream from the hill
Z_o	roughness scale of the flow
R_r	roughness Reynolds number $(U_\star Z_o/\nu)$
$U_\star$	surfsce friction velocity
P	potential power ratio
ΔS_F	fractional speed-up ratio
ΔT_u	fractional-variation in streamwise turbulence intensity
ν	kinematic viscosity
α	power index in the boundary-layer power-law profile

Subscripts

R	reference location
δ	boundary-layer thickness

INTRODUCTION

Considerable efforts have been devoted in the last two decades to the understanding of flow structures over non-uniform terrains and, in particular, flow over hills or escarpments. The use of boundary-layer wind tunnel (BLWT) facilities to carry out experimental studies on such flows is a fairly common practice. The studies provide results of important practical value as far as wind energy siting selection is concerned.

In early 1981, a major project was undertaken at AES to obtain a detailed, reliable set of full-scale data describing the atmospheric boundary-layer flow over a low, isolated, three-dimensional hill (Askervien) in Scotland. Mathematical and wind-tunnel simulation studies were also launched in order to assess the faithfulness with which they can reproduce the prototype flow characteristics.

This paper is based on the wind-tunnel simulation of neutrally-stable atmospheric boundary layer flow over the Askervien hill in the AES BLWT. The main features of the simulation technique are presented, along with a very brief discussion of the results. It is worth mentioning that similar simulations with different conditions (e.g. surface roughness, model scale, measuring techniques, wind-tunnel size, etc.) have been carried out at two other institutes: University of Canterbury, New Zealand and University of Oxford, England. Cross comparison between results from the different simulations and the full-scale experiment will be the subject of subsequent publications. An overview of the entire project and an outline of the full-scale results are given in Ref. 1. More details about the AES wind-tunnel simulation can be found in Ref. 2.

SITE DESCRIPTION

Askervein hill (Fig. 1) is located on the western side of the Island of South Uist in the Outer Hebrides of Scotland. Its maximum height is about 116m above the flat, uniform terrain surrounding it on all but the eastern side. It is elliptical in planform (Fig. 2) with a major axis of about 2 km. and a minor axis of about 1 km., thereby producing slopes ranging from about 0.25 to about 0.12 depending on wind directions. The four prevailing wind directions recorded during the full-scale experiment in September and October, 1983 were parallel to azimuthal directions 280, 235, 210 and 165 as shown in Fig. 2. The hill surface is relatively uniform, covered with short heather, grass, low scrub and flat rock. This surface can be characterized as "flat, open country" in the wind engineering sense. Data was measured at several locations along three "measuring" lines shown also in Fig. 2. For purposes of the wind-tunnel experiment, all positions were assigned consecutive "location" numbers as shown in the same figure. In this paper the lines ASW-ANE and AASW-AANE will be referred to as Lines A and AA respectively. The point HT in Fig. 2 refers to the hill top, while CP refers to the centre point of the model. The hill-half length (as seen from direction parallel to the hill minor axis) is about 225 m. A "reference" location was selected in the southwest uniform terrain surrounding the hill, at a distance of 2.7 km. from the CP.

Fig. 1 Photograph of the Askervein Hill from azimuthal direction 210°

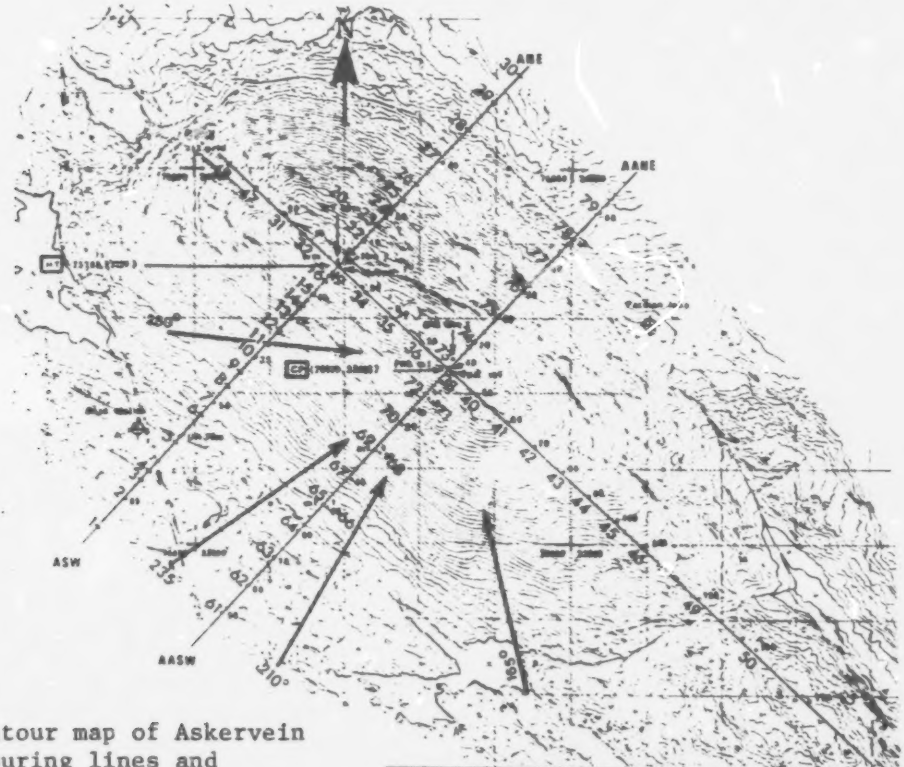

N
ANE
AANE
ASW
AASW
235°
250°
210°
165°
ASKERVEIN HILL TOWER LOCATIONS 1983
WIND-TUNNEL LOCATION NUMBER
10/35 FULL-SCALE POSITION IDENTIFIER

Fig. 2 Detailed contour map of Askervein showing measuring lines and locations. Contour interval is 2m, with some 1m contours also included

THE WIND-TUNNEL MODEL AND DATA ACQUISITION SYSTEM

The AES BLWT is an open-circuit type, with test-section dimensions of 1.83 m height, 2.44 m width and 18.3 m length. It is driven by 2.44 diameter fixed-pitch axial fan at the downstream end of the test section, powered by 75 HP motor. The tunnel roof can be adjusted to control the longitudinal pressure gradient in the test section. For the purpose of the present simulation, a zero-gradient was established before installation of the model. The air speed is continuously variable between 1 to 18 m s^{-1}. Turbulence intensity of the free-stream is maintained at relatively low level (0.5%) by using the usual flow-conditioning devices in the settling chamber, in addition to a honeycomb at the test section entrance.

The Askervein model was built to an undistorted length scale of 1:1200 from polyurethene foam. The model diameter was 2.337 m (2.80 km in full scale) centred on CP location. A 6-foot flat sheet of the same material was placed upstream of the model so that no change of roughness condition took place.

Data acquired using a standard DISA constant temperature anemometry system. The oupput analogue signals were low-pass filtered, then conditioned to fall within certain voltage limits, and finally digitized. Digital signals were processed in a host micro-computer which was also used for subsequent data analysis and plotting. Special procuedures have been developed for data acquisition at large-slope hill locations. Details about measuring techniques are given in Ref. 3.

SIMILARITY REQUIREMENTS FOR WIND-TUNNEL SIMULATION

The two basic similarity requirements which should be fulfilled are the geometrical and dynamic similarities. As for the former, the model and the prototype hill were geometrically similar with all important terrain features and the average surface roughness correctly represented without scale distorsion in any direction. The dynamic similarity, on the other hand, required that the ratio of the inertia to viscous forces (represented by Reynolds number) be the same for both the model and prototype flow. This could not be achieved since the nominal flow speed in the tunnel was about the same as that of the prototype flow, though the characteristic scale of the model was smaller by a factor of 1200. Therefore, the model flow was aerodynamically smooth (as indicated by $R_r = 0.16$ at the reference location), while the prototype flow was aerodynamically rough ($R_r = 670$ at the reference location).

Most of the boundary-layer characteristics of the approach flow, however, were similar. The two flows were characterized by a power-law profile (with the same power index) for the complete boundary layer and a logarithmic profile for the surface layer which extends about 100 m in full scale. The boundary layer thickness was proportionate for both flows. The aerodynamic roughness length was 2.5 cm for the prototype and 0.6 cm for the model flow. More details about the similarity requirements in general and the approach flow similarity in particular are given in Ref. 2.

ANALYTICAL DETAILS

The flow descriptive parameters, which are relevant to the results presented in this paper are:

1. Time-average of the streamwise velocity component $\overline{U}$.

2. Streamwise turbulence intensity component,

$$T_u = \left[\frac{1}{T} \int_o^T u^2 \, dt\right]^{\frac{1}{2}} / \overline{U}$$

3. Fractional speed up, ΔS_F, which is a measure of the variation in streamwise mean velocity at height (Z - h) above a local hill point of elevation h, with respect to the velocity at the same relative height at the reference upstream location.

$$\Delta S_F = [\overline{U}(Z) - \overline{U}_R \, (Z - h)] \; / \; \overline{U}_R \, (Z - h)$$

4. Fractional-variation in turbulence intensity, ΔT_u, defined similarly as above

$$\Delta T_u \, (Z) = [T_u(Z) - T_{uR} \, (Z-h)] \; / \; T_{uR} \, (Z - h)$$

5. The potential power ration, P, which is a measure of the average power at any point above the hill relative to the power at the reference location for a corresponding height:

$$P = [\overline{U}(Z) \; / \; \overline{U}_R \, (Z - h)]^3$$

Normalized versions of the above-mentioned dimensional parameters were used. The normalization process reduces the effects of undesirable factors contributing to errors in velocity measurements, (e.g. temporal and spatial inhomogeneity of the tunnel flow, hot-wire drift, ... etc) and consequently highlights the role of the model geometry on the speed variation. Complete details about the normalization process are given in Ref. 4.

SAMPLE RESULTS

Vertical profiles of the mean streamwise velocity components were measured at several locations along the hill. Since the power-law profile defined as

$$(\overline{U}/\overline{U}_\delta) = (Z \; / \; Z_\delta)^\alpha$$

is commonly used for vertical extrapolation of wind speeds along the entire boundary-layer, it has been fitted to each of the measured profiles to examine its validity. Fig. 3 shows the development of the mean velocity profiles along line A for mean wind direction 210 , together with the similar profile at the reference location. (Note that heights in all figures are given in full-scale). It is clear that, except for the thin layer in the lowest 3 m, the power law is maintained as the flow passes along the hill front.

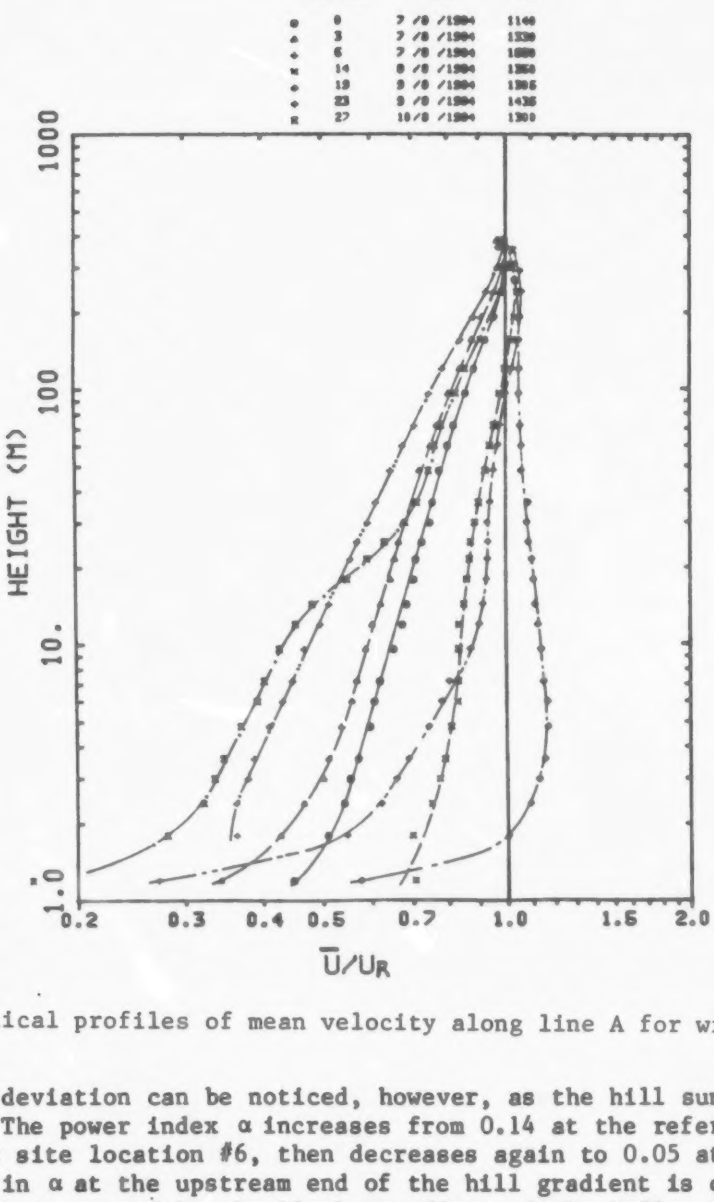


Fig. 3 Vertical profiles of mean velocity along line A for wind direction 210°

Considerable deviation can be noticed, however, as the hill summit is approached. The power index α increases from 0.14 at the reference location to about 0.22 at site location #6, then decreases again to 0.05 at location #16. The increase in α at the upstream end of the hill gradient is due to the flow slowness which is caused by the blockage effect of the hill. The flow starts to accelerate at location #10 (i.e. where the hill height ≃ H/3) and reaches a maximum speed at Z = 5m above the summit point. The maximum fractional speed-up ratio is 1.04. (i.e. 104% increase in speed relative to the upstream value at the same height). A similar trend has been found along line AA. Fig. 4 shows a horizontal profile of the fractional speed-up, ΔS_F, along AA for mean wind direction 210. Three wind-tunnel measured profiles are shown at three constant heights: Z = 3, 10 and 50 m, together with the field-measured profile at Z = 10m. It can be seen that the desirable accelerated flow region extends upstream of the hill summit to the point where the local hill height is 0.9 of the summit height. The agreement of the field-measured profile with the corresponding wind-tunnel profile confirms the reliability of both measurements (aside from data handling and instrument errors, field data may be questioned because of its relatively short-term acquisition and averaging period (Ref. 1), while wind-tunnel data may be questioned because of the incomplete similarity with the prototype flow). The accelerated flow also occupies most of the area upstream of the hill ridge, particularly for wind directions 210 and 235, where the mean flow becomes perpendicular to the ridge. Fig. 5 shows another set of horizontal profiles of ΔSF along the ridge at $Z = 10$ m for four mean wind directions: 210°, 235°, 165° and 280°. The data confirms the conclusion of Frost and Shieh (Ref. 5) that the magnitude and extent of accelerated flow is larger for large-aspect-ratio terrain whose major axis is perpendicular to the mean flow. The aspect ration, L/H, which is a measure of the blockage caused by the hill, is shown in the following table for each mean wind direction, together with the average values of fractional speed-up ratio and the potential power ratio along the ridge. These parameters seem to be correlated.

Mean Wind Direction	Hill Aspect Ratio	Average $\Delta S_{\bar{F}}$ Along the Ridge	Average Power Ratio Along the Ridge
280	8.3	0.31	2.25
235	16.7	0.60	4.10
210	16.7	0.60	4.10
165	11.0	0.40	2.74

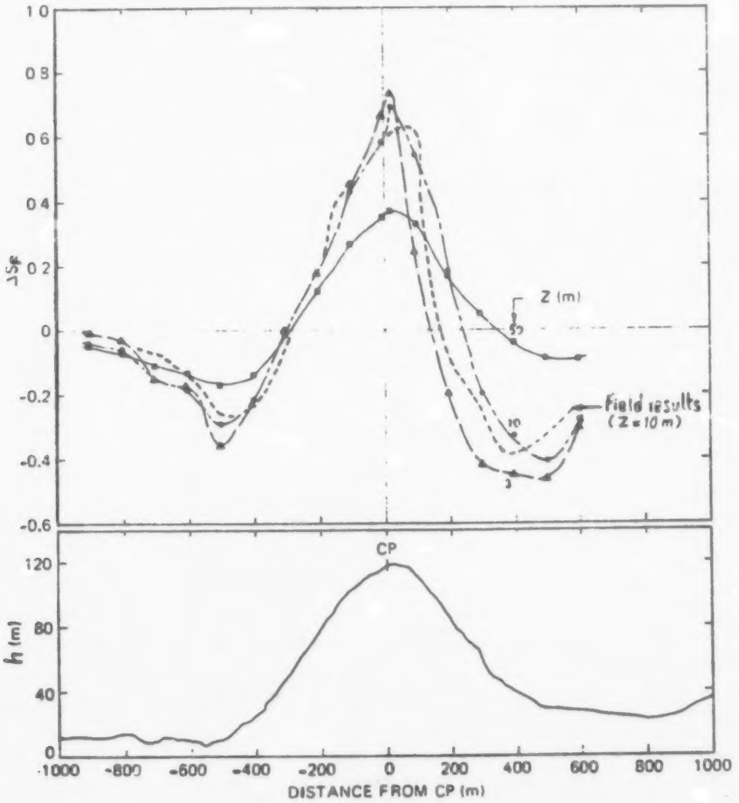


Fig. 4 Horizontal profiles of fractional speed-up ratio along line AA for wind direction 210°

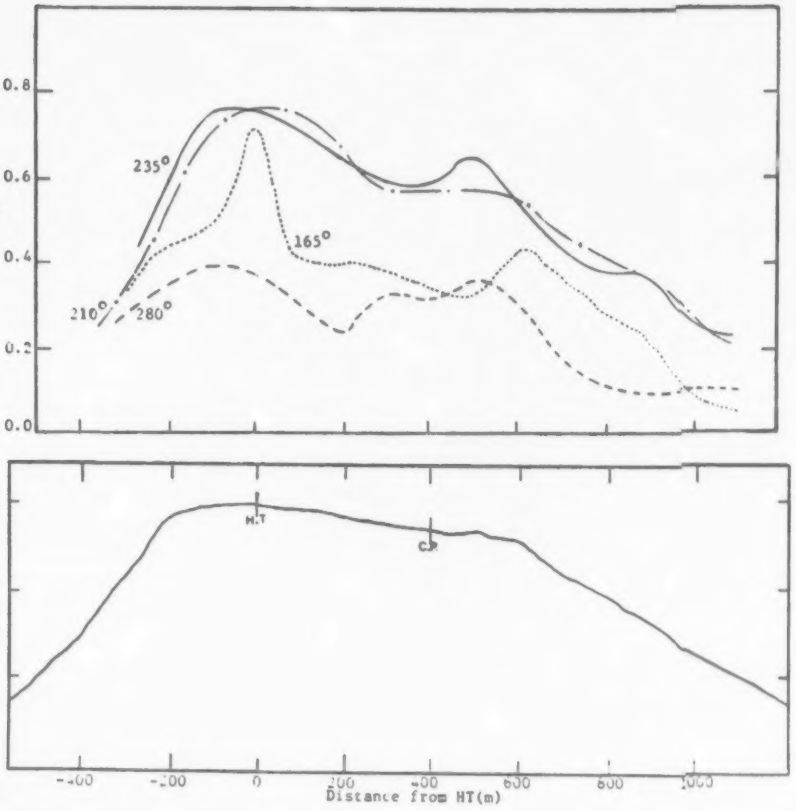


Fig. 5 Horizontal profiles of fractional speed-up ratio along the hill ridge at Z = 10 m for four wind directions

As for the turbulence characteristics of the flow over the hill, results suggest that upstream flow blockage is associated with high turbulence intensities, which drop gradually as the flow accelerates. The development of the streamwise turbulence intensity profiles is demonstrated in Fig. 6 for the mean wind direction 235 along line A. The smallest values of Tu occur near the hill top at heights above 10m from the surface, while large values were experienced at the back of the hill. Figures 7 and 8 show horizontal profiles along line A of fractional speed-up and fractional-variation in Tu respectively for the four wind directions involved. Separated flow zones, defined here as regions of high turbulence intensities and small mean velocities, can be noticed at the lee side of the hill. The location and size of these zones are sensitive to the variation in wind directions as shown in the figures (e.g. no flow separation is associated with the mean wind direction 165°). It should be noticed, however, that it is difficult to derive conclusions about the flow separation experimentally, partly because of the complex nature of the hill, and also because of the complicated character of the three-dimensional flow separation. (see Ref. 6). Siting WECS on local distorsions is not recommended because of the high turbulence level developed around them (as shown in Fig. 8 for the cavity located 600 m upstream the hill top). It should also be mentioned that, since the three-dimensional characteristics of the flow became dominant at certain mean flow directions (namely 165 and 280 in this experiment), the interpretation of the acquired data at those directions will be subject to error.

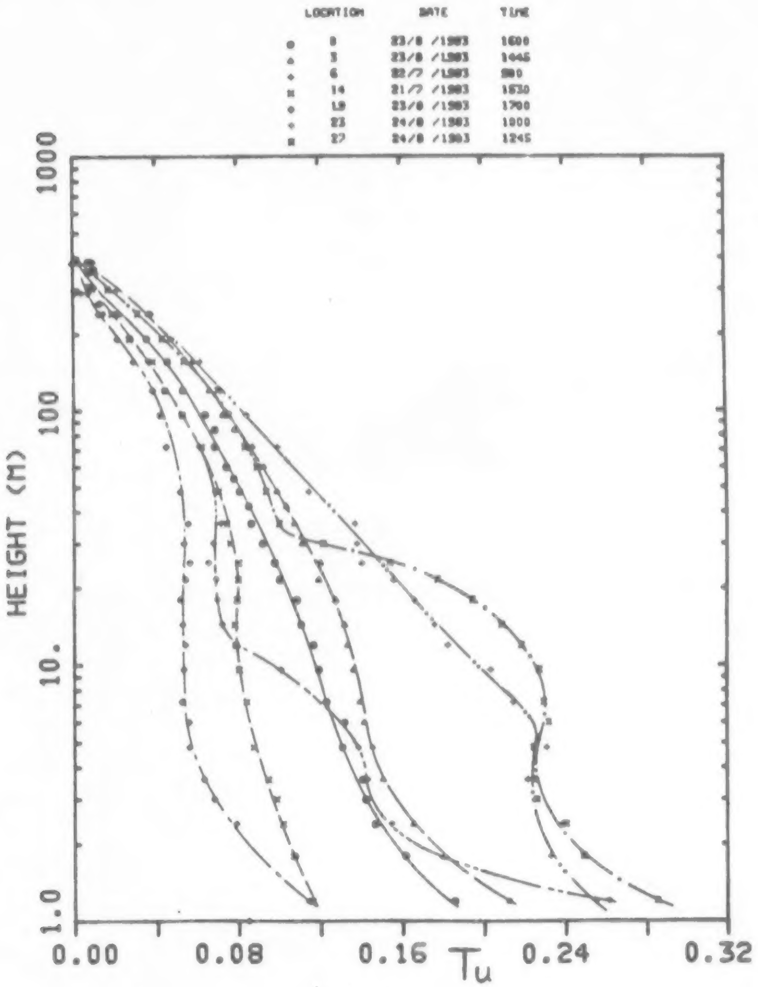


Fig. 6 Vertical profiles of streamwise turbulence intensity along line A for wind direction 235°

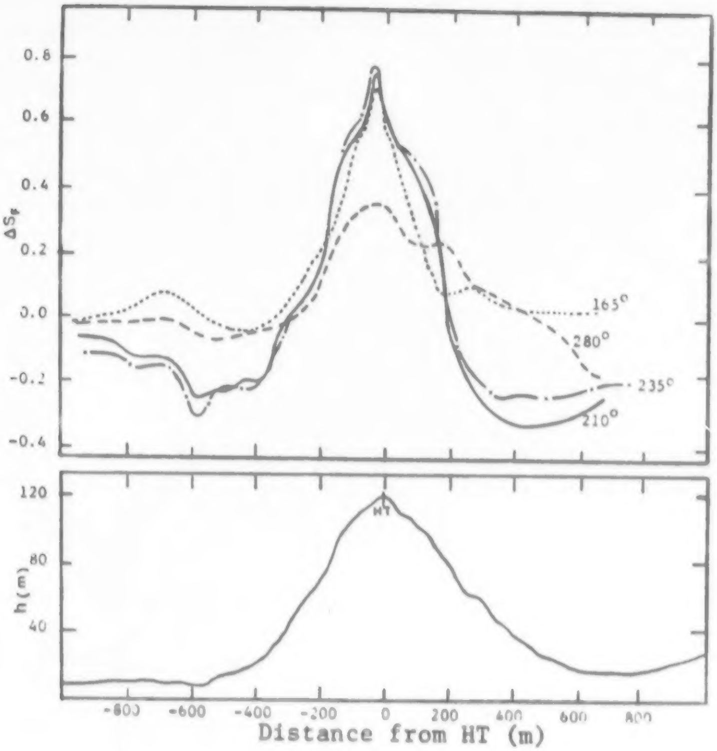


Fig. 7 Horizontal profiles of fractional speed-up ratio along line A at Z = 10m, for four wind directions

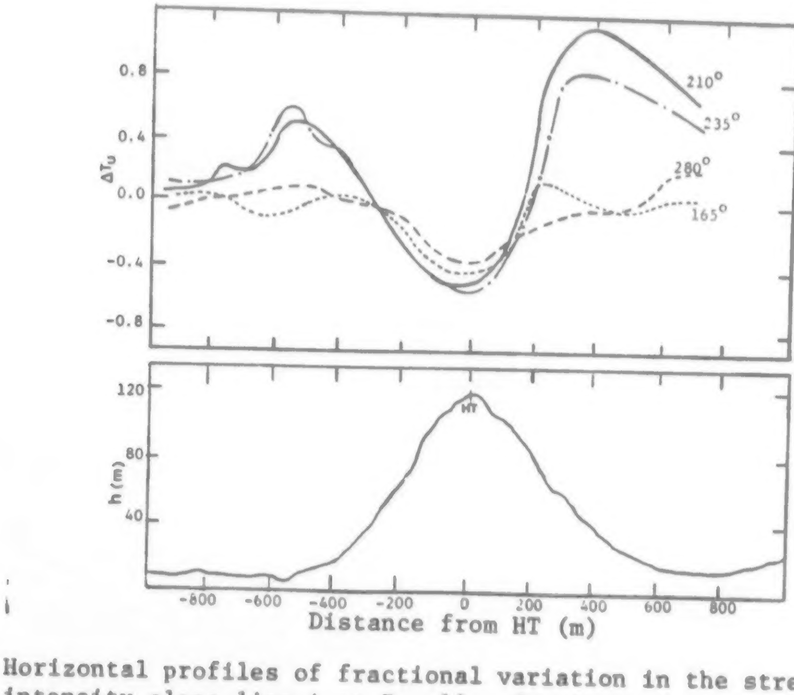


Fig. 8 Horizontal profiles of fractional variation in the streamwise turbulence intensity along line A at Z = 10m, for four wind directions

More results are available on turbulence intensities in lateral and cross directions, as well as on time correlation between turbulence components. Development of power spectra of the streamwise and lateral velocity components is also available and will be the subject of forthcoming publication.

CONCLUSIONS

A wind-tunnel-modelling study of neutrally-stable atmospheric boundary layer flow over an isolated hill, has been carried out. Similarity requirements were generally fulfilled, except for the flow aerodynamic roughness. The goals were twofold: firstly, to examine the validity of the wind-tunnel-modelling approach, by verifying its results against the field results, and secondly, to provide more data on mean flow and turbulence characteristics over the hill with a view to determining areas of enchanced wind potential (i.e. preferred WECS sites). As for the first goal, results agree quantitatively with the field measurements along the hill front, especially when the oncoming flow is perpendicular to the hill major axis. Otherwise, only qualitative agreement was reported. With respect to the second goal, regions of accelerated flow were identified along the hill ridge, together with regions of highly turbulent or separated flow at the lee side of the hill and around protrusions and cavities. The sensitivity of accelerated and separated flow regions to variations in the mean wind direction has also been established.

ACKNOWLEDGMENT

The overall Askervein project is a cooperative effort involving a number of researchers including Dr. Hans Teunissen from AES whose contribution in discussing some of the results presented herein is acknowledged. Partial support for this study was provided by Energy Mines and Resources, Canada (OERD) through the Wind Energy Research and Development Program of the National Research Council of Canada.

REFERENCES

1. Taylor, P.A. and Teunissen, H.W.: "The Askervein Hill Project = Report on September/October, 1983, Main Field Experiment". Report #MSRB-84-6, Atmospheric Environment Service, Toronto, Canada, Dec. 1984

2. Teunissen, H.W. and Shokr, M.E.: "The Askervein Hill Project = Wind tunnel simulation (smooth model) at length scale 1:1200". Report #MSRB-85-1, Atmospheric Environment Service, Toronto, Canada, 1985

3. Shokr, M.E. and Teunissen, H.W.: "Use of hot-wire anemometery in the AES boundary-layer wind tunnel, with particular reference to flow over hill models", Report #MSRB-86-1, Atmospheric Environment Service, Toronto, Canada, 1986

4. Shokr, M.E.: "Data processing and analysis system for flow measurements in the AES boundary-layer wind tunnel with particular reference to flow over hill models." Atmospheric Environment Service, Research Report (to be published).

5. Frost, W and Shieh, C.F.: "Wind characteristics over complex terrain relative to WECS siting", AIAA Wind Energy Conference, Boulder, Colorado, 1980

6. Chang, P.K.: "Separation of flow", Pergamon press 1970

ALIMENTATION HYBRIDE EOLIENNE-DIESEL D'UN EMETTEUR RADIO

Jean-Marc Arseneault, Yves Jean, Claude Jolicoeur et Guy Turgeon

Groupe-Conseil Therméca
énergies nouvelles
mécanique
électricité

1026, rue Saint-Jean, bureau 403, Québec,
Qué., G1R 1R7 Tél.: (418) 692-0321

-et-

Berthier Deschamps
Ingénieur

Berthier Deschamps et Associés

INGÉNIEURS-CONSEILS

- Civil
- Électrique, mécanique
- Gérance de projets
- Lignes de transmission
- Télécommunications

1783, rue Ste-Famille
Ste-Foy, Qué.
G2G 1M4
Tél. Bur.: (418) 871-7260
Rés.: (418) 832-6958

CLIENT : Radio MF Charlevoix - CIHO MF 96,3
315, rue Cartier-Nord
C.P. 160
St-Hilarion, Qc
G0A 3V0

Projet réalisé grâce à la participation financière du Ministère des Mines, des Ressources et des Energies. Programme ENERDEMO.

INTRODUCTION

Pour une meilleure couverture possible de la région montagneuse de Charlevoix, et pour éviter l'implantation de plusieurs répétitrices, Radio MF Charlevoix Inc a décidé d'installer son émetteur au sommet du mont des Eboulements à environ 2 500 pieds au-dessus du niveau du fleuve.

Vu l'ampleur des coûts requis pour le raccordement du site émetteur au réseau d'Hydro-Québec, les consultants, le Groupe-Conseil Therméca Inc et Berthier Deschamps et Associés, ont choisi d'alimenter de façon autonome les équipements d'émission.

Les services climatiques d'Environnement Canada évaluent la vitesse moyenne annuelle des vents entre 7 m/s et 8 m/s. L'utilisation de l'énergie éolienne s'avérait donc être une solution logique pour une alimentation autonome.

Différentes configurations ont été étudiées en comparaison avec l'installation d'une ligne électrique aérienne, entre autres:

- une alimentation basée sur deux groupes électrogènes diésel opérant en alternance

- une alimentation jumelant une éolienne de moyenne puissance de grande fiabilité à un groupe électrogène diésel d'appoint

- une alimentation hybride éolienne-diésel avec stockage sur accumulateurs plus un groupe électrogène à essence pour les urgences.

Cette dernière solution fut retenue pour les raisons énumérées ci-après:

- coût d'investissement de base compétitif

- coûts d'opération faibles

- fiabilité

- possibilité de subventions

1. LE MONTAGE:

Le montage des composantes constituant l'alimentation hybride est illustré à la figure 1. On peut diviser ce montage en six groupes, soit:

A - l'aérogénérateur
B - le stockage
C - le système UPS (Uninteruptible Power Supply)
D - le système de contrôle de la génératrice diésel
E - la génératrice diésel
F - le système d'émission

A - L'aérogénérateur

L'aérogénérateur est principalement constitué d'une éolienne Extrawatt dont le diamètre du rotor mesure 6,5 mètres. La puissance mécanique captée du vent est transmise a un alternateur synchrone possédant les caractéristiques nominales suivantes:

208 V, 60 Hz à 1 800 tpm et une puissance nominale de 12,5 kW

La multiplication de vitesse entre le rotor et la génératrice est assurée par une courroie dentée (X2.2) et une boite d'engrenage (X3.3). La hauteur de la tour est de 12 m au-de[illegible] du sol.

Un dispositif de régulation basée sur une réduction de l'angle d'attaque des pales permet au rotor de ne pas dépasser une vitesse de rotation limite même lorsque la charge est nulle. Ce facteur rend l'utilisation de cette éolienne très sécuritaire car les risques d'emballement du rotor sont diminués.

Cependant, contrairement à la régulation par décrochage aérodynamique, cette régulation ne permet pas d'obtenir des vitesses de rotation constantes, ce qui occasionne des variations de tension à mesure que le vent change.

Pour alimenter l'émetteur et permettre de charger les accumulateurs, l'énergie électrique produite par l'éolienne doit être continue et à tension fixe. On a donc placé à la suite de l'alternateur un transformateur et un pont de diodes pour abaisser et redresser la tension du courant alternatif produit par l'éolienne.

Pour palier aux variations de tension dûes à la vitesse variable du rotor, l'alternateur est employé à environ 70% de sa puissance nominale et une boucle de contrôle agissant sur l'excitation de l'inducteur de la machine électrique est introduite pour maintenir une tension constante à la sortie du pont de diodes. Ce principe permet de produire à partir de l'éolienne une énergie électrique capable de charger les accumulateurs à 48 V sur une grande plage de vitesses du vent.

B - LE STOCKAGE

Le stockage de l'énergie éolienne produite pendant la période nocturne ou de l'énergie excédentaire non consommée par l'émetteur lors des journées de grands vents est faite sur des accumulateurs à décharge profonde ("Deep cycle") de type plomb-acide. Un compteur d'ampères-heures bidirectionnel permet de connaitre en tout temps l'état de charge des batteries. Ainsi on peut éviter la surcharge des accumulateurs en réduisant la tension de charge flottante en ajustant le point de consigne de la boucle de régulation de tension de l'éolienne.

De même, afin d'éviter la décharge complète des batteries, le compteur d'ampères-heures envoie un signal de démarrage au contrôle du groupe électrogène pour lancer le moteur diésel lorsque le niveau d'énegie emmagasiné devient trop bas. Ce seuil d'énergie nommé la Réserve Minimale d'Energie est maintenu pour permettre un temps d'intervention minimale en cas de panne du groupe électrogène. A l'arrivée du technicien au site émetteur, celui-ci branche le réseau local du site sur la génératrice d'urgence à essence.

C - LE SYSTEME UPS (Uninterruptible Power Supply)

Pour accroître la fiabilité du montage et assurer le meilleur agencement possible entre les composantes, un système d'alimentation ininterrompue (UPS) de marque Nife a été préféré à un assemblage de composantes de provenances diverses.

Le système UPS est composé principalement d'un redresseur régularisé à thyristors permettant de transformer du courant alternatif en courant continu. Le redresseur contrôlé pourra être utilisé pour charger les batteries à partir de l'énergie excédentaire produite par la génératrice diésel lorsque celle-ci alimente l'émetteur MF. La pièce maitresse du système UPS est sans doute l'onduleur à transistors de puissance produisant à sa sortie une onde sinusoîdale de qualité nécessaire aux équipements électroniques.

D - SYSTEME DE CONTROLE DU DIESEL

Ce système de contrôle se charge:

1) du démarrage du moteur diésel sur réception du signal de bas niveau du système de stockage

2) de l'arrêt du moteur à la fin de l'émission journalière

De plus, les contrôles des circuits de protection du moteur diésel (pression d'huile, niveau d'eau) sont situés à l'intérieur de l'armoire de contrôle du diésel. Ces circuits de protection coupent l'alimentation en carburant du moteur. Tous ces contrôles sont indépendants du système UPS.

E - GENERATRICE DIESEL

Un groupe électrogène de type primaire fut choisi pour le projet. Le groupe est constitué d'un moteur diésel à 2 cylindres de marque Lister de 9,5 kW. Le moteur est refroidi à l'antigel et est couplé à un alternateur de 6 kW de marque Kato fournissant un courant alternatif à 240 V monophasé. La vitesse de rotation du groupe électrogène est de 1 200 tpm. Le moteur peut opérer de 10 000 à 12 000 heures sans révision générale (overhaul).

Le moteur diésel est relié à trois réservoirs de carburant totalisant une capacité de 3 400 l (750 gal).

F - EMISSION

La principale charge sur le réseau local est l'émetteur MF consommant environ 4 000 W pour émettre avec une puissance rayonnée de 1 500 W (RF). L'émetteur de marque Thomson est entièrement transistorisé et possède plusieurs protections. Il est protégé entre autres contre la surchauffe et contre les surtensions. Cet émetteur est donc bien adapté au type de réseau local où les caractéristiques de l'onde de tension ne sont pas aussi stables que celles d'un grand réseau.

Radio MF Charlevoix prévoit une programmation comprenant 18 heures par jour de diffusion. En considérant que les accessoires de ventilation et les équipements d'émission autres que l'émetteur consomment au total environ 500 W, on estime les besoins énergétiques du site émetteur à 30 000 kWh par année.

2- LES PERFORMANCES DU SYSTEME

Les performances aérodynamiques et électiques de l'éolienne ont été approximées à partir de rapports produit par l'IREQ en 1980 1 et l'Université Laval en 1983 2 sur des aérogénérateurs de conception similaire. Une estimation de la courbe de puissance électrique en fonction de la vitesse du vent en a été tirée et est présentée à la figure 2.

Une première approximation de la production énergétique annuelle de l'éolienne peut se faire en intégrant le produit de la fonction de la densité de probabilité du vent par celle de la puissance électrique de l'éolienne.

$$E_{éol} = 8\ 760 \times \int_{Va}^{Vb} P\ (v) \times F\ (v)\ dv$$

Va = vitesse d'amorçage du rotor
Vb = vitesse d'arrêt du rotor
P (v) : puissance en fonction du vent (figure 2)
F (v) : approximation de la densité de probabilité du vent sur le site par la distribution de Rayleigh
$E_{éol}$: énergie annuelle produite par l'éolienne

Dans notre cas, la fonction de densité de probabilité des vents du site n'étant pas disponible, nous l avons approximé par une une distribution de Rayleigh.

$$F(v) = \frac{\pi v}{2\bar{V}^2}\ e^{-\frac{\pi}{4}\left(\frac{v}{\bar{V}}\right)^2}$$

où $\bar{V}$ est la vitesse moyenne annuelle du vent.

Avec une vitesse moyenne annuelle des vents de 7 m/s, on trouve une production d'énergie par l'éolienne de 27 500 kWh.

En introduisant le rendement des différentes composantes du montage, il est possible de déterminer l'énergie électrique à la sortie de l'onduleur.

Rendement des composantes:

N_1 - transformateur 95%
N_2 - pont de diodes 99%
N_3 - accumulateurs 80%
N_4 - onduleurs 80%

Le rendement des accumulateurs ne s'applique qu'à l'énergie transigée à travers les batteries. On estime que cette énergie équivaut à 40% de la production totale de l'éolienne. De plus, il est nécessaire d'introduire un facteur d'utilisation de l'énergie "F.U." pour tenir compte des pertes d'énergie dues à la trop faible capacité du stockage ou aux pertes occasionnées par les arrêts de l'aérogénérateur pour son entretien.

Le rendement global du système pour l'énergie éolienne est donc:

$$N_G = N_1 \times N_2 \times N_4 \times N_1 \times (40\% \times N_3 + 60\%) \times F.U.$$

$$N_G = .95 \times .99 \times .8 \times .95 \times (.40 \times .8 + .60) \times .75 = 50\%$$

Energie électrique à la sortie de l'onduleur = 27 500 X 50% = 13 750 kWh

La consommation annuelle du site émetteur est estimée à 30 000 kWh. La différence devra être comblée par le groupe électrogène soit 16 250 kWh. Cette quantité d'énergie représente environ 5 750 litres de carburant diésel. (.35 l/kWh).

CONCLUSION

On constate que l'implantation d'une station hybride éolienne-diésel telle que proposée permet d'économiser environ 46% de la consommation de carburant par rapport a une installation fonctionnant seulement avec un groupe électrogène. De plus, la longévité du moteur ainsi que la fréquence des entretiens mécaniques se trouvent modifiées par un facteur deux.

Malheureusement, les nombreux niveaux de transformation de l'énergie entre l'entrée d'un kW mécanique au rotor éolien et sa sortie sous forme électrique occasionne une forte baisse du rendement global du montage. Pour réduire ces pertes d'énergie, il serait donc préférable, lorsque cela est possible, d'alimenter des appareils fonctionnant en courant continu. Dans ce cas, le rendement global serait meilleur et les investissements de base réduits.

Ajoutons qu'un système hybride est à prime abord plus complexe qu'un système conventionnel d'alimentation. Il exige du personnel d'entretien doté d'une bonne formation aussi bien en mécanique qu'en électronique.

Pour confirmer les chiffres avancés dans cette article, le projet comporte une seconde phase qui consite à surveiller et à enregistrer différents paramètres du système sur une période d'un an. Ces paramètres sont les suivants:

- vitesse et direction du vent
- puissance fournie par l'éolienne
- puissance fournie par le groupe électrogène diésel
- consonmation de l'émetteur
- état de charge des batteries
- consommation de carburant
- quantité d'énergie transigée à travers le stockage

Parallèlement à cette expérimentation, un programme de simulation horaire de l'alimentation hybride sera développé. Ces deux outils permettront dans un avenir rapproché de raffiner les séquences d'opération du système d'alimentation hybride éolienne-diésel pour l'amener à fonctionner à son rendement optimal.

Alimentation hybride éolienne-diésel d'un émetteur radio.

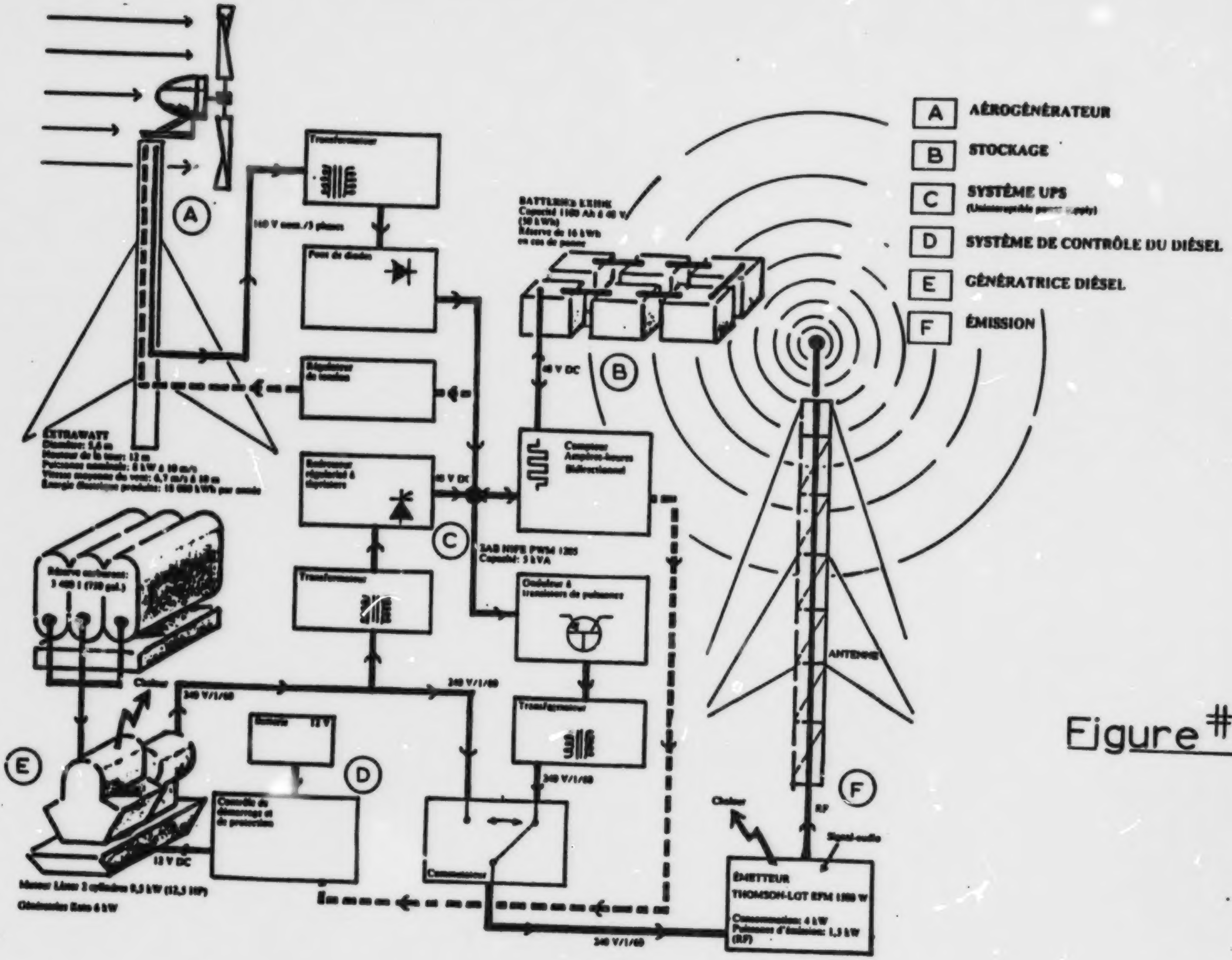

A AÉROGÉNÉRATEUR
B STOCKAGE
C SYSTÈME UPS
D SYSTÈME DE CONTRÔLE DU DIÉSEL
E GÉNÉRATRICE DIÉSEL
F ÉMISSION
A
B
C
D
E
F
Transformateur
Pont de diodes
Régulateur de tension
Redresseur régularisé à thyristors
Transformateur
EXTRAWATT
Diamètre: 5,6 m
Hauteur de la tour: 12 m
BATTERIES EXIDE
Capacité 1100 Ah à 48 V
(50 kWh)
Réserve de 16 kWh
en cas de panne
48 V DC
Compteur Ampères-heures Bidirectionnel
Capacité: 3 kVA
Onduleur à transistors de puissance
Transformateur
240 V/1/60
240 V/1/60
240 V/1/60
240 V/1/60
Commutateur
Chaleur
12 V
Contrôle de démarrage et de protection
12 V DC
ANTENNE
RF
Chaleur
ÉMETTEUR
Consommation: 4 kW
(RF)

Figure #1

Puissance électrique de l'éolienne extrawatt (5,6 mètre ϕ).
en fonction de la vitesse du vent.

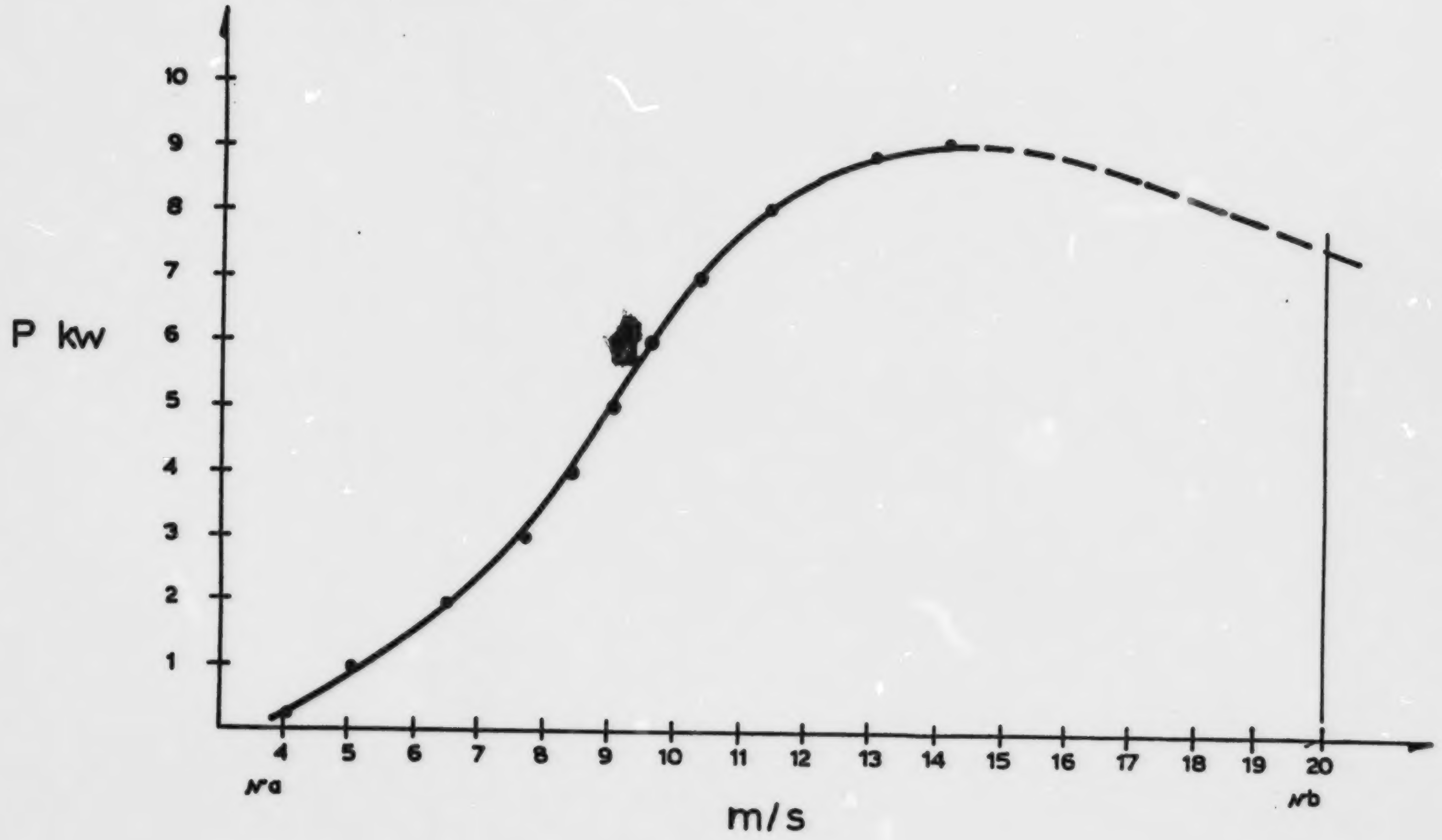


Figure #2

ANNEXE A

TABLEAU DE CALCUL DE L'ENERGIE EOLIENNE PRODUITE ANNUELLEMENT POUR LE SITE DU MONT DES EBOULEMENTS

v = 7 m/s

P(v) (kW)	V m/s	F(v)	F(v).P(v)	Surface des trapèzes
.2	4	.0992	.0198	
1	5	.1074	.1074	.0636
2	6.5	.1058	.2117	.2393
3	7.7	.0954	.2863	.2988
4	8.4	.0869	.3476	.2219
5	9.0	.0788	.3938	.2224
6	9.6	.0703	.4215	.2446
7	10.3	.0603	.4220	.2952
8	11.2	.0461	.3846	.3630
9	13	.0278	.2499	.5710
8.7	16	.0085	.0737	.4854
8.2	18	.0032	.0263	.1000
7.5	20	.0011	.0079	.0342

Intégration numérique :
(règle trapèzoïdale)

Puissance moyenne : Pm = 3.1 kW

Energie annuelle Pm X 8760 = 27 500 kW

Bibliographie

1 SAULNIER, B., SUNDERLAND, J. et D. MAROIS : Mesures des performances de l'aérogénérateur d'héliowatt Inc, Rapport no 2514, Institut de Recherche de Hydro-Québec, 23 déc. 1981.

2 LAVOIE, J., JEAN, Y. et J. DICKINSON (Groupe de recherche Energie éolienne de l'Université Laval : Essais effectués à St-Victor de Beauce sur l'éolienne modèle "Boréal" de 5,6 m de la compagnie Hélio-Beauce Inc.

BANQUET ADDRESS

NOTES POUR UN DISCOURS DU SOUS-MINISTRE ASSOCIÉ À L'ENERGIE, M. ALBAN D'AMOURS

DEVANT
L'ASSOCIATION CANADIENNE
D'ÉNERGIE ÉOLIENNE

LUNDI, LE 27 OCTOBRE 1986

CHÂTEAU FRONTENAC

QUÉBEC

Mesdames,
Messieurs,

Introduction

C'est avec grand plaisir que j'ai accepté l'invitation de votre comité d'organisation de venir vous adresser la parole, ici, ce soir, à l'issue de cette première journée de votre colloque.

Je suis très heureux de vous souhaiter la bienvenue ici dans le Vieux-Québec, que vous aurez l'occasion de découvrir, j'espère, au cours des prochaines journées. Il s'agit de la deuxième conférence de l'Association canadienne de l'Énergie Éolienne et, à sa façon, elle témoigne de la vigueur croissante de cette industrie, de même que de la structuration de plus en plus importante des activités reliées aux économies d'énergie et aux énergies nouvelles.

Tout récemment, M. John Ciaccia, ministre de l'Energie et des Ressources du Québec, prononçait une allocution à l'occasion du 1er Congrès et du premier anniversaire de l'Association québécoise pour la maîtrise de l'énergie. Cette association, qui compte déjà quelques centaines de membres et s'intéresse à des domaines connexes, est également témoin de l'importance grandissante des activités reliées aux économies d'énergie et aux nouvelles sources d'énergie.

Lors du premier choc pétrolier, en 1973, l'ensemble de ces activités relevait dans une large mesure de la futurologie. On peut maintenant constater que les participants de ces industries ont des préoccupations très concrètes de nature commerciale, et que ces préoccupations témoignent du degré de maturité de ces activités quelque 10 à 15 ans plus tard.

LES CHOCS PÉTROLIERS DES ANNÉES '70 ONT EN EFFET ENTRAÎNÉ UNE RÉÉVALUATION COMPLÈTE DES PRINCIPALES ORIENTATIONS EN MATIÈRE D'ÉNERGIE. ILS ONT AMENÉ PAR AILLEURS UN INTÉRÊT ACCRU POUR LES ÉCONOMIES D'ÉNERGIE, ET LES TECHNIQUES D'ÉNERGIES NOUVELLES.

CE SOIR, JE TENTERAI DONC TOUT D'ABORD DE VOUS EXPOSER COMMENT LE QUÉBEC A RÉAGI À CETTE NOUVELLE SITUATION D'INSÉCURITÉ D'APPROVISIONNEMENTS PÉTROLIERS ET DE PRIX DE L'ÉNERGIE CROISSANTS. NOUS EXAMINERONS, PAR LA SUITE, LES MOYENS QU'A MIS EN OEUVRE LE QUÉBEC, PLUS PARTICULIÈREMENT AUX NIVEAUX DES ÉCONOMIES D'ÉNERGIE ET DES ÉNERGIES NOUVELLES, POUR ATTEINDRE SES OBJECTIFS.

I - POLITIQUE ÉNERGÉTIQUE

LA CRISE DE L'ÉNERGIE DES ANNÉES '70 POSAIT TOUT D'ABORD LE PROBLÈME DE L'INSÉCURITÉ DES APPROVISIONNEMENTS. EN EFFET, L'OPEP, QUI CHERCHAIT D'ABORD À PROVOQUER DES HAUSSES DES PRIX, EST DEVENU, PENDANT UN CERTAIN TEMPS, UNE ARME EMPLOYÉE PAR LES PAYS ARABES POUR OBTENIR DES MODIFICATIONS À LA SITUATION POLITIQUE ET MILITAIRE AU MOYEN-ORIENT.

DES MENACES DE PÉNURIE SE SONT FAITES SENTIR, ET L'OBJECTIF DE SÉCURITÉ DES APPROVISIONNEMENTS, QUI N'ÉTAIT PAS TOTALEMENT ABSENT DANS LES CONSIDÉRATIONS POLITIQUES ANTÉRIEURES, EST SOUDAINEMENT DEVENU UN OBJECTIF DE PREMIER PLAN. DANS TOUS LES PAYS CONSOMMATEURS D'ÉNERGIE, LES GOUVERNEMENTS ONT DONC DÛ CHERCHER À RÉPONDRE À CE PROBLÈME EN PREMIER LIEU.

CEPENDANT, LA SÉCURITÉ DES APPROVISIONNEMENTS N'ÉTAIT PAS LE SEUL OBJECTIF SOUS-TENDANT LES POLITIQUES ÉNERGÉTIQUES. DANS L'ENSEMBLE DES PAYS INDUSTRIALISÉS, UNE ACTION APPROPRIÉE SUR LE SECTEUR ÉNERGÉTIQUE EST APPARUE COMME UN MOYEN PRIVILÉGIÉ D'ASSURER ET DE RENFORCER LA CROISSANCE ÉCONOMIQUE. AU QUÉBEC, PLUS PEUT-ÊTRE QUE PARTOUT AILLEURS, LE DÉVELOPPEMENT EST AINSI

DEVENU UN AUTRE OBJECTIF FONDAMENTAL DE LA POLITIQUE ÉNERGÉTIQUE GOUVERNEMENTALE, NE SERAIT-CE QU'EN RAISON DE L'IMPORTANCE DES INDUSTRIES DE L'ÉNERGIE DANS LA PRODUCTION INTÉRIEURE ET LA CONSOMMATION. C'EST DANS CE SENS QUE, DEPUIS DE NOMBREUSES ANNÉES, LE QUÉBEC S'EST EMPLOYÉ À UTILISER AU MAXIMUM SES AVANTAGES COMPARATIFS DANS CERTAINES FORMES D'ÉNERGIE, ET À EN FAIRE UNE VÉRITABLE STRATÉGIE DE DÉVELOPPEMENT.

A) SÉCURITÉ DES APPROVISIONNEMENTS

AU NIVEAU DE LA SÉCURITÉ DES APPROVISIONNEMENTS D'ABORD, LA STRATÉGIE DU GOUVERNEMENT A ÉTÉ RELATIVEMENT SIMPLE. LE PREMIER ÉLÉMENT DE CETTE STRATÉGIE CONSISTAIT À FAVORISER LA PÉNÉTRATION RAPIDE ET MASSIVE DE LA SEULE FORME D'ÉNERGIE TIRÉE DES RESSOURCES PROPRES DU QUÉBEC, L'HYDRO-ÉLECTRICITÉ. DÉJÀ AU DÉBUT DES ANNÉES '70, ÉTAIT LANCÉ L'IMPORTANT PROJET DE LA BAIE JAMES, QUI ALLAIT PERMETTRE, VERS LA FIN DE LA DÉCENNIE, CETTE PÉNÉTRATION IMPORTANTE DE L'ÉLECTRICITÉ DANS LE BILAN ÉNERGÉTIQUE. EN UN PEU PLUS DE DIX ANS, DE 1973 À 1985, LA PART DE L'ÉLECTRICITÉ DANS LE BILAN ÉNERGÉTIQUE PASSAIT DE 20,2% À 39,2%.

LE DEUXIÈME ÉLÉMENT DE CETTE STRATÉGIE ÉTAIT LE DÉVELOPPEMENT DES AUTRES FORMES D'ÉNERGIE AUTOCHTONES. LA PLUS IMPORTANTE DE CELLES-CI EST BIEN CONNUE, PUISQU'IL S'AGIT DU BOIS DE CHAUFFAGE. IL EST DIFFICILE DE MESURER CORRECTEMENT L'IMPORTANCE DE CETTE FORME D'ÉNERGIE, À TRAVERS LES ANNÉES, À CAUSE DE L'ABSENCE DE DONNÉES FIABLES SUR LA PRODUCTION OU LA CONSOMMATION. CEPENDANT, DES TRAVAUX DE QUANTIFICATION EFFECTUÉS AU SEIN DU MINISTÈRE DE L'ENERGIE ET DES RESSOURCES NOUS PERMETTENT DE CONSTATER UNE CROISSANCE TRÈS SIGNIFICATIVE DE L'IMPORTANCE DE CETTE FORME D'ÉNERGIE ENTRE 1972 ET 1985, ET ON CONSIDÈRE QUE CELLE-CI, INCLUANT LES DÉCHETS URBAINS, REPRÉSENTE MAINTENANT 8,2% D'UN BILAN ÉNERGÉTIQUE ÉLARGI À LA BIOMASSE, PAR RAPPORT À 4,4% EN 1972.

Dans ces deux cas, il s'agissait de ressources énergétiques du Québec facilement exploitables et rentables, et dont les technologies étaient bien établies.

Le Québec s'intéressait également à l'exploitation des autres formes d'énergie non conventionnelles dont il dispose, telles l'énergie solaire ou l'énergie éolienne. Cependant, le degré d'avancement des technologies en cause, surtout il y a dix ans, ainsi que la concurrence provenant des formes d'énergie beaucoup moins chères au Québec, telle l'hydro-électricité, ne permettait pas de miser sur une contribution très significative de ces filières énergétiques à un terme rapproché.

Le troisième élément de cette politique, l'augmentation de l'efficacité énergétique, constituait à bien des égards la solution la moins coûteuse et la plus rentable de toutes les avenues possibles. C'est ainsi qu'on établissait dès 1975 un premier programme d'aide à l'isolation thermique des maisons. D'autres programmes furent créés par la suite. Nous reviendrons d'ailleurs sur ce sujet un peu plus loin.

Les économies d'énergie sont apparues progressivement comme une des solutions majeures pour résoudre le coût croissant des importations de pétrole, et assurer également une plus grande sécurité énergétique. On peut dire que, dans une très large mesure, le succès de ces efforts de réduction de la consommation, consentis par l'ensemble des pays consommateurs, ont porté fruit et ont amené la chute actuelle des prix du pétrole.

Au Québec, la croissance annuelle de la consommation d'énergie, qui avait été de 6,1% au cours des années '60, s'est abaissée à 0,8% de 1973 à 1976 et à -1,3% entre 1976 et 1985. Il s'agit là d'un succès assez éclatant.

EN QUATRIÈME LIEU, LE QUÉBEC A COMPLÉTÉ CETTE STRATÉGIE, AXÉE SUR LA PROMOTION DES ÉNERGIES AUTOCHTONES ET DES ÉCONOMIES D'ÉNERGIE, PAR UN APPUI À LA PÉNÉTRATION DU GAZ NATUREL. EN EFFET, IL S'AGISSAIT D'UNE SOURCE D'ÉNERGIE, ICI NON PAS QUÉBÉCOISE MAIS CANADIENNE, POUR LAQUELLE NOUS AVIONS ACCÈS À D'IMMENSES RÉSERVES ET DONT L'APPROVISIONNEMENT N'ÉTAIT PAS SOUMIS À DES MENACES D'INTERRUPTION POUR DES RAISONS DE POLITIQUE INTERNATIONALE. PAR AILLEURS, LE GAZ NATUREL PRÉSENTAIT DES AVANTAGES CERTAINS AU NIVEAU ÉCONOMIQUE. ENTRE 1973 ET 1985, LA PART DU GAZ NATUREL, DANS LE BILAN ÉNERGÉTIQUE QUÉBÉCOIS, EST PASSÉE DE 5,0% À 15,3%. LA CONSTRUCTION DU GAZODUC ENTRE MONTRÉAL, QUÉBEC, LE SAGUENAY/LAC SAINT-JEAN ET LES CANTONS DE L'EST A PERMIS CETTE PÉNÉTRATION MASSIVE, QUI EST EN VOIE DE SE CONSOLIDER.

AU TOTAL, LA SITUATION ÉNERGÉTIQUE DU QUÉBEC A ÉTÉ AINSI BOULEVERSÉE EN UN PLUS DE DIX ANS. GRÂCE AUX ÉCONOMIES D'ÉNERGIE, À L'UTILISATION ACCRUE DE L'ÉLECTRICITÉ, DU GAZ NATUREL ET DES ÉNERGIES NON CONVENTIONNELLES, LA CONSOMMATION QUÉBÉCOISE DU PÉTROLE BRUT EST TOMBÉE, ENTRE 1979 ET 1985, DE 512 000 BARILS PAR JOUR À 274 000 BARILS PAR JOUR. LA PART DU PÉTROLE DANS LE BILAN ÉNERGÉTIQUE DU QUÉBEC N'EST PLUS QUE DE 44,3%, COMPARATIVEMENT À 72,8% IL Y A DOUZE ANS. ON NE PEUT QUE SOULIGNER L'IMPACT TRÈS POSITIF QU'A EU UNE TELLE ÉVOLUTION, SUR LA SÉCURITÉ DE NOS APPROVISIONNEMENTS.

B) DÉVELOPPEMENT ÉCONOMIQUE

PERMETTEZ-MOI MAINTENANT D'ATTIRER VOTRE ATTENTION SUR LES ASPECTS DE DÉVELOPPEMENT ÉCONOMIQUE QU'ONT ENGENDRÉ UNE TELLE POLITIQUE. PAR EXEMPLE, LA PÉNÉTRATION DE L'ÉLECTRICITÉ ÉTAIT LE PREMIER ÉLÉMENT DE L'AMÉLIORATION DE SÉCURITÉ DES APPROVISIONNEMENTS. ELLE A ÉTÉ RENDUE POSSIBLE PAR LES INVESTISSEMENTS

MASSIFS D'HYDRO-QUÉBEC DANS L'AMÉNAGEMENT DE LA RIVIÈRE LA GRANDE, À LA BAIE JAMES, AU COÛT DE QUELQUE 16 MILLIARDS DE DOLLARS, ET QUI ONT FAIT PASSER LA CAPACITÉ DE PRODUCTION DE 11 150 MÉGAWATTS EN 1973 À 23 510 MÉGAWATTS EN 1985.

DE TELS INVESTISSEMENTS ONT EU DES RETOMBÉES IMPORTANTES. IL Y A EU D'ABORD DES RETOMBÉES EN TERMES DE CRÉATION DIRECTE D'EMPLOIS. EGALEMENT, À UN NIVEAU INDIRECT, CES INVESTISSEMENTS HYDRO-ÉLECTRIQUES ONT CONDUIT AU DÉVELOPPEMENT DE FIRMES DE GÉNIE-CONSEILS PARMI LES PLUS IMPORTANTES AU MONDE, ET À LA CROISSANCE DE SOCIÉTÉS MANUFACTURIÈRES CHARGÉES DE LA FABRICATION DES ÉQUIPEMENTS DES GRANDES CENTRALES ET DES LIGNES DE TRANSMISSION.

CETTE PÉNÉTRATION DE L'ÉLECTRICITÉ S'EST FAITE DANS LA PLUPART DES SECTEURS. DANS LE SECTEUR RÉSIDENTIEL, PAR EXEMPLE, L'ÉLECTRICITÉ EST ALLÉE CHERCHER JUSQU'À 80% DES CONSTRUCTIONS DES NOUVELLES HABITATIONS. DANS LE SECTEUR INDUSTRIEL, ON A ASSISTÉ, ENTRE AUTRES, GRÂCE À UN IMPORTANT PROGRAMME DE CONVERSION DES CHAUDIÈRES, À UNE PERCÉE TRÈS SIGNIFICATIVE DANS LES INDUSTRIES DES PÂTES ET PAPIERS. DE TELS PROGRAMMES ONT PERMIS PAR AILLEURS, RETOMBÉE NON NÉGLIGEABLE, UNE MODERNISATION RAPIDE DES ÉQUIPEMENTS.

D'AUTRES INDUSTRIES SONT VENUES S'INSTALLER AU QUÉBEC, AFIN DE BÉNÉFICIER DES TARIFS PARTICULIÈREMENT AVANTAGEUX DE L'ÉLECTRICITÉ. JE PENSE, ENTRE AUTRES, À L'ÉTABLISSEMENT DE PÉCHINEY ET À L'AGRANDISSEMENT DES INSTALLATIONS DE REYNOLDS, ET PLUS RÉCEMMENT À L'ANNONCE PAR LA SOCIÉTÉ NORSK-HYDRO DE LA CONSTRUCTION D'UNE USINE DE MAGNÉSIUM À BÉCANCOUR.

DANS UNE CERTAINE MESURE, LES OBJECTIFS DE MARCHÉ RELATIFS À L'ÉLECTRICITÉ SONT EN VOIE D'ÊTRE ATTEINTS. LE QUÉBEC DOIT DONC SE TOURNER VERS LES MARCHÉS D'EXPORTATIONS POUR ASSURER LA REPRISE DU DÉVELOPPEMENT ACCÉLÉRÉ DES RESSOURCES HYDRAULIQUES.

LE MARCHÉ INTÉRIEUR DU QUÉBEC EST EN VOIE DE FAIRE LE PLEIN DE SON POTENTIEL DE CROISSANCE ET SEUL LE MARCHÉ D'EXPORTATION PEUT APPORTER LA CROISSANCE DE LA DEMANDE NÉCESSAIRE POUR JUSTIFIER DES AMÉNAGEMENTS TRÈS IMPORTANTS.

A CÔTÉ DE L'HYDRO-ÉLECTRICITÉ, LES EFFORTS AU NIVEAU DES ÉCONOMIES D'ÉNERGIE ONT ÉGALEMENT EU DES RETOMBÉES ÉCONOMIQUES SIGNIFICATIVES. LES PROGRAMMES D'ISOLATION DES MAISONS, TANT DU GOUVERNEMENT FÉDÉRAL QUE DU GOUVERNEMENT DU QUÉBEC, ONT AMENÉ LA CRÉATION D'UNE NOUVELLE ACTIVITÉ INDUSTRIELLE QUI EST VENUE RELANCER LA CONSTRUCTION DOMICILIAIRE. DE MÊME, ON PEUT DIRE QUE LES MESURES D'ÉCONOMIES D'ÉNERGIE ONT MODIFIÉ SUBSTANTIELLEMENT LES TECHNIQUES DE CONSTRUCTION ET AJOUTÉ À LA VALEUR INTRINSÈQUE DES HABITATIONS.

AU NIVEAU DES ÉCONOMIES D'ÉNERGIE DANS L'INDUSTRIE, QUE CE SOIT LA PETITE ET MOYENNE ENTREPRISE OU LA GRANDE INDUSTRIE, ON A ASSISTÉ À L'ÉMERGENCE D'UN NOUVEAU TYPE DE GÉNIE-CONSEIL. PLUSIEURS ENTREPRISES DE MONTRÉAL ONT MAINTENANT COMME PRINCIPALE ACTIVITÉ LE CONSEIL EN ÉCONOMIES D'ÉNERGIE. DE MÊME, DES ENTREPRISES ONT ÉTÉ CRÉÉES POUR PRENDRE EN MAIN LA GESTION ÉNERGÉTIQUE DES GRANDS ÉTABLISSEMENTS, ET RÉDUIRE LEUR FACTURE DE COMBUSTIBLE ET D'ÉLECTRICITÉ.

ENFIN, LA MAÎTRISE DE L'ÉNERGIE A DONNÉ NAISSANCE À D'IMPORTANTES ACTIVITÉS DE FABRICATION D'ÉQUIPEMENTS DONNANT UN PLUS HAUT RENDEMENT ÉNERGÉTIQUE.

SUR LE PLAN DES ÉNERGIES NOUVELLES, IL FAUT SOULIGNER L'ÉMERGENCE AU QUÉBEC D'UNE INDUSTRIE DE L'ÉNERGIE SOLAIRE PARMI LES MIEUX STRUCTURÉES DE L'AMÉRIQUE DU NORD. CETTE INDUSTRIE OCCUPE 80% DU MARCHÉ CANADIEN, ET EST TRÈS ACTIVE SUR LES MARCHÉS D'EXPORTATIONS. L'ACTION DU GOUVERNEMENT A PERMIS DE TIRER PROFIT, AU PLAN ÉNERGÉTIQUE, DE L'IMPLANTATION PAR LES MUNICIPALITÉS, D'INSTALLATIONS D'INCINÉRATION DES DÉCHETS URBAINS.

DES EFFORTS IMPORTANTS ONT ÉTÉ CONSENTIS, TANT AU NIVEAU DE LA RECHERCHE QUE DE LA COMMERCIALISATION, POUR FAIRE DE L'HYDROGÈNE UN NOUVEAU VECTEUR ÉNERGÉTIQUE. DE MÊME, EN CE QUI CONCERNE L'ÉNERGIE ÉOLIENNE, LES EFFORTS DE RECHERCHE ONT ÉTÉ SOUTENUS. DES SOMMES IMPORTANTES ONT ÉTÉ AFFECTÉES À LA CONSTRUCTION D'UNITÉS DE DÉMONSTRATION.

EN CE QUI CONCERNE LE BOIS DE CHAUFFAGE ET LES RÉSIDUS FORESTIERS, ON NE PEUT PAS PARLER À PROPREMENT DIT D'ÉNERGIES NOUVELLES, MAIS PLUTÔT D'UNE ÉNERGIE REDÉCOUVERTE. LES CHIFFRES QUE JE VOUS AI DONNÉ TOUTE À L'HEURE SONT ASSEZ ÉLOQUENTS ET MONTRENT L'IMPORTANCE QU'OCCUPE L'ÉNERGIE TIRÉE DU BOIS DANS LE BILAN ÉNERGÉTIQUE DU QUÉBEC. DE NOMBREUSES USINES DE PÂTES ET PAPIERS OU SCIERIES ONT CONVERTI LEURS INSTALLATIONS DE CHAUFFAGE POUR POUVOIR UTILISER LES RÉSIDUS PROVENANT DE LEURS PROPRES ACTIVITÉS. LA MULTIPLICATION DU NOMBRE D'HABITATIONS CHAUFFÉES AU BOIS A ÉGALEMENT SUSCITÉ UNE RECRUDESCENCE DE LA COUPE DE BOIS ET DE SON COMMERCE.

ENFIN, LE QUÉBEC A CONSENTI UN EFFORT MAJEUR AUX FINS DE VALORISATION DE LA BIOMASSE DANS SON USINE DE MÉTHANISATION DU BOIS À SAINT-JUSTE-DE-BRETENIÈRES.

LE TABLEAU NE SERAIT PAS COMPLET SI L'ON N'ÉVOQUAIT PAS L'IMPORTANCE DES INVESTISSEMENTS CONSENTIS POUR LE DÉVELOPPEMENT DU RÉSEAU DE TRANSPORT ET DE DISTRIBUTION DU GAZ NATUREL. DANS CES DEUX ACTIVITÉS, LES SOMMES DÉPASSENT LE MILLIARD DE DOLLARS ENTRE 1980 ET 1985. PAR L'INTERMÉDIAIRE DE SOQUIP, ET AVEC L'AIDE DE PROGRAMMES SPÉCIFIQUES DU GOUVERNEMENT FÉDÉRAL ET DU GOUVERNEMENT DU QUÉBEC, GAZ MÉTROPOLITAIN, INC., MAINTENANT NOVERCO, EST DEVENUE L'UNE DES PLUS IMPORTANTES SOCIÉTÉS DE DISTRIBUTION DU GAZ AU CANADA.

COMME CHACUN LE SAIT, LA DISPONIBILITÉ DU GAZ NATUREL EST PARFOIS UN FACTEUR DÉTERMINANT DE LOCALISATION DES ENTREPRISES. DE NOMBREUX PROCÉDÉS INDUSTRIELS DÉPENDENT DE LA DISPONIBILITÉ DE CETTE SOURCE D'ÉNERGIE. PAR AILLEURS, L'ACCÈS DANS LES DIFFÉRENTS CENTRES INDUSTRIELS DU QUÉBEC À UNE AUTRE SOURCE D'ÉNERGIE, RELATIVEMENT MOINS CHÈRE, A AMENÉ UNE COMPÉTITIVITÉ ACCRUE ENTRE LES DIFFÉRENTES SOURCES D'ÉNERGIE, ET AMÉLIORÉ LES CONDITIONS DE RENTABILITÉ, PARTICULIÈREMENT POUR LES INDUSTRIES FORTES CONSOMMATRICES D'ÉNERGIE.

COMME ON LE VOIT, L'ACTION GOUVERNEMENTALE DANS LE SECTEUR ÉNERGÉTIQUE A EU POUR CONSÉQUENCE DIRECTE ET INDIRECTE D'AMENER AU QUÉBEC DES INVESTISSEMENTS CONSIDÉRABLES EN INFRASTRUCTURE, DE DÉVELOPPER LE SAVOIR-FAIRE DES ENTREPRISES DE GÉNIE-CONSEILS, DE CRÉER DE NOUVELLES ACTIVITÉS, TANT AU NIVEAU DES ÉNERGIES NOUVELLES QUE DES ÉCONOMIES D'ÉNERGIE, D'APPORTER À L'INDUSTRIE MANUFACTURIÈRE QUÉBÉCOISE UN PLUS HAUT NIVEAU DE COMPÉTITION AU NIVEAU DE SES SOURCES D'APPROVISIONNEMENT, ET FINALEMENT DE RÉDUIRE CONSIDÉRABLEMENT, POUR LE QUÉBEC, L'INFLUENCE DE LA HAUSSE DES PRIX DU PÉTROLE SUR SA BALANCE COMMERCIALE.

JE VOUDRAIS MAINTENANT CONSACRER LA DEUXIÈME PARTIE DE CET EXPOSÉ À L'ACTION SPÉCIFIQUE CONSENTIE PAR LES POUVOIRS PUBLICS AFIN DE FAVORISER LES ÉCONOMIES D'ÉNERGIE ET DE PROMOUVOIR LES NOUVELLES FILIÈRES ÉNERGÉTIQUES.

II - INTERVENTION GOUVERNEMENTALE EN ÉCONOMIES D'ÉNERGIE ET EN ÉNERGIES NOUVELLES

COMME JE LE SOULIGNAIS TOUT À L'HEURE, C'EST EN TRÈS GRANDE PARTIE GRÂCE AU SUCCÈS DE CES POLITIQUES DE SUBSTITUTION, D'ÉCONOMIES D'ÉNERGIE ET DE DÉVELOPPEMENT D'ÉNERGIES NOUVELLES, DANS LES PAYS CONSOMMATEURS, QUE L'ON A ASSISTÉ À UNE BAISSE IMPORTANTE DU PRIX DU PÉTROLE.

IRONIQUEMENT, LE SUCCÈS DE L'ENSEMBLE DES MESURES PALIATIVES À LA HAUSSE DES PRIX DU PÉTROLE A AINSI ENTRAÎNÉ LA CHUTE DES PRIX QUI À SON TOUR REND PLUS DIFFICILE LA POURSUITE DU DÉVELOPPEMENT DES ÉNERGIES DE SUBSTITUTION OU ENCORE DES TECHNIQUES D'ÉCONOMIES D'ÉNERGIE. CET ÉVÉNEMENT NOUS AMÈNE À REPENSER NOS POLITIQUES ÉNERGÉTIQUES, À SE DEMANDER SI LES ORIENTATIONS SUIVIES JUSQU'À MAINTENANT SONT TOUJOURS VALABLES, ET À S'INTERROGER SUR LE RÔLE DE L'ETAT DANS L'ATTEINTE DES OBJECTIFS DÉSIRÉS.

VERS LE MILIEU DES ANNÉES '70, LES GOUVERNEMENTS ONT TENTÉ DE PARER AU PLUS PRESSÉ ET DE MINIMISER POUR LES CONSOMMATEURS L'IMPACT DES HAUSSES DE PRIX. PARALLÈLEMENT, UN CERTAIN NOMBRE DE PROGRAMMES ONT ÉTÉ MIS SUR PIED, POUR AIDER LES CONSOMMATEURS À ÉCONOMISER L'ÉNERGIE. ON A VU LA CRÉATION, AU QUÉBEC, DU PROGRAMME D'ISOLATION DES MAISONS (PIM), ET AU FÉDÉRAL, D'UN PROGRAMME SIMILAIRE. PAR LA SUITE, LE GOUVERNEMENT DU QUÉBEC A TRANSFORMÉ SON PROGRAMME AXÉ SUR LES SUBVENTIONS AUX TRAVAUX EN UN PROGRAMME D'AIDE AU DIAGNOSTIC, APPELÉ ENERGAIN, ET GÉRÉ PAR HYDRO-QUÉBEC.

LE PROGRAMME D'ISOLATION DES MAISONS FUT EN VIGUEUR DE 1978 À 1982, ET PERMIT DE VERSER PRÈS DE 100 000 SUBVENTIONS POUR UN TOTAL DE 22,5 MILLIONS DE DOLLARS. ENTRE 1981 ET 1985, LE PROGRAMME ENERGAIN A PERMIS LA RÉALISATION DE PRÈS DE 250 000 ANALYSES ÉNERGÉTIQUES DANS LES HABITATIONS QUÉBÉCOISES, COUVRANT AINSI QUELQUE 10% DE L'ENSEMBLE DU PARC DE LOGEMENTS AU QUÉBEC.

LE SECTEUR RÉSIDENTIEL A ÉGALEMENT BÉNÉFICIÉ DE PROGRAMMES DE SUBVENTION À LA CONVERSION OFFERTS PAR LE GOUVERNEMENT FÉDÉRAL ET LES ENTREPRISES HYDRO-QUÉBEC ET GAZ MÉTROPOLITAIN, INC. CES PROGRAMMES ONT LARGEMENT CONTRIBUÉ À ACCROÎTRE LA PART RELATIVE DE L'ÉLECTRICITÉ ET DU GAZ DANS LA CONSOMMATION D'ÉNERGIE, TOUT EN AMÉLIORANT L'EFFICACITÉ DES SYSTÈMES DE CHAUFFAGE.

Bien que les programmes de subvention aient connu un succès certain, ils étaient relativement coûteux. Les difficultés budgétaires constantes des gouvernements les ont amené à se réorienter vers une aide plus subtile, dirais-je, et plus indirecte. Le gouvernement du Québec, comme je le disais, a transformé son programme de subvention d'isolation des maisons en un programme de diagnostic. De même, il a axé sur le diagnostic son intervention dans le secteur industriel.

Il faut se rappeler, en premier lieu, le programme Energiebus qui effectuait, sur le site même, à l'aide d'équipements informatiques transportés par des petits autobus, des analyses énergétiques. Ce programme découlait d'une entente fédérale-provinciale se terminant en 1980. Devant la grande popularité de celui-ci, le Québec le prolongea, à ses frais, au cours des années 1980 à 1982.

En juillet 1982, une nouvelle entente fédérale-provinciale permettait d'offrir un nouveau programme intitulé "Programme national de vérification du rendement énergétique" ou encore P.N.V.R.E. Dans le cadre de ce programme, le Bureau des économies d'énergie effectuait des analyses énergétiques plus poussées, et créait un nouveau volet de subvention aux études de faisabilité.

Ce programme a été suivi d'un autre programme intitulé "Programme de productivité énergétique" qui comprenait essentiellement les mêmes composantes de vérification et de financement des analyses énergétiques. C'est ainsi que de 1983 à 1985, 882 entreprises ont fait l'objet d'analyses énergétiques. Elles ont réalisé des investissements totaux de 98 millions de dollars et en projettent 36 autres au cours des prochaines années. On estime que ces investissements ont créé au Québec près de 2 500 emplois.

PAR AILLEURS, 187 AUTRES ENTREPRISES ONT BÉNÉFICIÉ D'UNE ÉTUDE DE FAISABILITÉ. CES ÉTUDES QUI ONT SUSCITÉ DES INVESTISSEMENTS DE 21 MILLIONS DE DOLLARS N'ONT DEMANDÉ AU GOUVERNEMENT QUE DES SUBVENTIONS DE 2 MILLIONS DE DOLLARS.

ON ESTIME À PLUS DE 50 MILLIONS DE DOLLARS LES ÉCONOMIES D'ÉNERGIE ANNUELLES RÉALISÉES PAR CES INVESTISSEMENTS, CE QUI REPRÉSENTE UNE PÉRIODE DE RECOUVREMENT DES INVESTISSEMENTS D'UN PEU PLUS DE DEUX ANS.

CE NOUVEAU TYPE D'ACTION GOUVERNEMENTALE S'EST DONC RÉVÉLÉ EXTRÊMEMENT EFFICACE. LE BILAN TRÈS POSITIF, QUE JE VIENS DE DRESSER AU NIVEAU DES INVESTISSEMENTS, A AMENÉ LE MINISTÈRE DE L'ENERGIE ET DES RESSOURCES À ALLER CHERCHER DES CRÉDITS BUDGÉTAIRES ADDITIONNELS POUR PROLONGER LES SUBVENTIONS DES ÉTUDES DE FAISABILITÉ DU PROGRAMME DE PRODUCTIVITÉ ÉNERGÉTIQUE. LES PRESSIONS POUR LA PROLONGATION D'UN TEL PROGRAMME SONT VENUES À LA FOIS DU MILIEU DES ENTREPRISES BÉNÉFICIAIRES ET DU MILIEU DES ENTREPRISES DE GÉNIE-CONSEILS.

LE TROISIÈME TYPE D'INTERVENTION UTILISÉ PAR LE GOUVERNEMENT EST CELUI DE LA DIFFUSION DE L'INFORMATION. UN EFFORT DE PLUS EN PLUS IMPORTANT Y EST CONSACRÉ. EN EFFET, TRÈS SOUVENT, IL N'Y A PAS BESOIN DE SUBVENTIONS POUR AMENER LES INDUSTRIELS À SE PRÉVALOIR DE POSSIBILITÉS TECHNOLOGIQUES QUI PROCURENT DES TAUX DE RETOUR DE DEUX OU TROIS ANS. CE QUI MANQUE DANS BIEN DES CAS C'EST UNE INFORMATION ADÉQUATE SUR LES DERNIERS DÉVELOPPEMENTS TECHNOLOGIQUES.

UN DES RELAIS LES PLUS EFFICACES POUR TRANSMETTRE L'INFORMATION EST CELUI D'ASSOCIATION TELLE QUE LA VÔTRE. NOUS CROYONS EN EFFET QU'IL EST IMPORTANT QUE LES DIFFÉRENTS INTERVENANTS DES MILIEUX SE REGROUPENT POUR PERMETTRE DE PLUS NOMBREUX ÉCHANGES, AINSI QU'UN REGROUPEMENT DES INFORMATIONS DISPONIBLES DANS

L'ENSEMBLE DU SECTEUR. LA CRÉATION DE L'A.Q.M.E. A ÉTÉ UN ÉLÉMENT IMPORTANT DANS CETTE POLITIQUE DE DIFFUSION. LE DÉVELOPPEMENT DE VOTRE ASSOCIATION DEVRAIT ÉGALEMENT AIDER À CRÉER LES SYNERGIES NÉCESSAIRES À L'ÉVOLUTION DE VOTRE INDUSTRIE.

LE QUATRIÈME TYPE D'INTERVENTION EST L'AIDE À LA RECHERCHE, AU DÉVELOPPEMENT ET À LA DÉMONSTRATION. LES GOUVERNEMENTS INTERVINRENT À CE NIVEAU D'UNE FAÇON PLUS TRADITIONNELLE, EN SUBVENTIONNANT LES DIFFÉRENTS PROJETS DE RECHERCHE, DE DÉVELOPPEMENT ET DE DÉMONSTRATION QUI LUI ONT ÉTÉ SOUMIS ET QUI LUI PARAISSAIENT PARMI LES PLUS INTÉRESSANTS. LES GOUVERNEMENTS SONT INTERVENUS ÉGALEMENT PAR L'IMPLICATION DES LABORATOIRES DE RECHERCHE GOUVERNEMENTAUX.

C'EST AINSI QUE LE MINISTÈRE DE L'ENERGIE ET DES RESSOURCES A CONTRIBUÉ AUX EFFORTS DE RECHERCHE PAR L'OCTROI DE SUBVENTION DE CONTRATS POUR LA RÉALISATION DE PROJETS DE RECHERCHE ET DE DÉVELOPPEMENT, AINSI QUE D'ÉTUDES DE FAISABILITÉ EN ÉNERGIES NOUVELLES ET ÉCONOMIES D'ÉNERGIES. LES SOMMES OCTROYÉES PAR LA DIRECTION DES TECHNOLOGIES ET DES ÉNERGIES NOUVELLES, DU MINISTÈRE DE L'ENERGIE ET DES RESSOURCES, AU COURS DES DERNIÈRES ANNÉES, TOTALISENT PRÈS DE 5 MILLIONS DE DOLLARS À CE CHAPITRE.

LE MINISTÈRE DE L'ENERGIE ET DES RESSOURCES A ÉGALEMENT CONTRIBUÉ À LA FORMATION DES CHERCHEURS ET D'UNE MAIN-D'OEUVRE SPÉCIALISÉE DONT LE QUÉBEC A ET AURA BESOIN POUR L'EXPLOITATION DE CES NOUVELLES FORMES D'ÉNERGIE. UN CONCOURS DE BOURSES D'ÉTUDES ET DE RECHERCHE EN ÉNERGIE MIS SUR PIED EN COLLABORATION AVEC LE FONDS POUR LA FORMATION DE CHERCHEURS ET L'AIDE À LA RECHERCHE, A PERMIS D'ATTRIBUER PLUS D'UNE CINQUANTAINE DE BOURSES DE MAÎTRISE ET DE DOCTORAT DANS LES DISCIPLINES DIRECTEMENT RELIÉES DANS LES ÉNERGIES NOUVELLES.

ENFIN, LE GOUVERNEMENT DU QUÉBEC A CHERCHÉ À FAVORISER LA COMMERCIALISATION DES TECHNIQUES D'ÉCONOMIES D'ÉNERGIE ET D'ÉNERGIES NOUVELLES PAR LA CRÉATION D'UNE SOCIÉTÉ D'ETAT ENTIÈREMENT CONSACRÉE À CES ACTIVITÉS. IL S'AGIT BIEN SÛR DE NOUVELER, QUI EST MAINTENANT PROPRIÉTÉ À PART ENTIÈRE D'HYDRO-QUÉBEC.

LA SOCIÉTÉ HYDRO-QUÉBEC S'EST BEAUCOUP IMPLIQUÉE ÉGALEMENT DANS LE DÉVELOPPEMENT D'APPLICATIONS CONCRÈTES DE L'UTILISATION DES ÉNERGIES NOUVELLES. ELLE A D'AILLEURS PRIS LE CONTRÔLE DE NOUVELER DANS LE CADRE DE SA POLITIQUE DE DIVERSIFICATION. ELLE EST ACTIVEMENT ENGAGÉE DANS UN PROGRAMME D'ESSAI VISANT L'UTILISATION DE L'ÉNERGIE ÉOLIENNE POUR L'APPROVISIONNEMENT EN ÉLECTRICITÉ DES RÉGIONS ÉLOIGNÉES. DES RÉSULTATS POSITIFS À CE CHAPITRE AMÈNERAIENT PROBABLEMENT HYDRO-QUÉBEC À POUSSER PLUS AVANT SES ACTIVITÉS EN CE DOMAINE.

LE BILAN DES ACTIVITÉS DU GOUVERNEMENT DU QUÉBEC QUE JE VIENS DE TRACER EST CERTES DES PLUS POSITIFS. TOUTEFOIS, IL FAUT ÊTRE BIEN CONSCIENT QUE CE QUE NOUS AVONS FAIT EN MATIÈRE D'ÉCONOMIES D'ÉNERGIE ET DE RECHERCHE ET DÉVELOPPEMENT EN ÉNERGIES NOUVELLES NE CONSTITUE QU'UN APPORT MODESTE PAR RAPPORT À CE QUI S'EST FAIT PARTOUT AILLEURS DANS LE MONDE.

LA SITUATION DES APPROVISIONNEMENTS EN ÉNERGIE AU QUÉBEC NE PERMET SANS DOUTE PAS À CETTE TECHNOLOGIE DE CONNAÎTRE LE MÊME ESSOR QUE DANS D'AUTRES PAYS MOINS BIEN POURVUS EN APPROVISIONNEMENTS ÉNERGÉTIQUES. POURTANT, IL Y AURAIT ENCORE BEAUCOUP À FAIRE. EN EFFET, LE QUÉBEC COMME LE RESTANT DE L'AMÉRIQUE DU NORD, QUOIQUE DANS UNE MOINDRE MESURE, A UNE CONSOMMATION D'ÉNERGIE PAR UNITÉ DE PRODUCTION INTÉRIEURE NETTEMENT PLUS ÉLEVÉE QUE LA PLUPART DES PAYS EUROPÉENS ET LES AUTRES PAYS DE L'O.C.D.E.

CONCLUSION

COMME JE LE DISAIS PLUS TÔT, LA BAISSE DES PRIX DU PÉTROLE NOUS FORCE À RÉFLÉCHIR À NOUVEAU SUR LE RÔLE DES DIFFÉRENTES FILIÈRES ÉNERGÉTIQUES. IL EST HEUREUX DANS UNE CERTAINE MESURE QUE CETTE BAISSE NE SOIT PAS SURVENUE PLUS TÔT. EN EFFET, LA PLUPART DES FILIÈRES ÉNERGÉTIQUES ONT PU SE POSITIONNER AVANTAGEUSEMENT SUR LE MARCHÉ QUÉBÉCOIS. ELLES ONT RÉUSSI À DÉVELOPPER LEURS TECHNOLOGIES ET À METTRE EN PLACE LEUR RÉSEAU DE COMMERCIALISATION, DE TELLE SORTE QUE LA SITUATION ACTUELLE DE CONCURRENCE ENTRE LES DIFFÉRENTES FILIÈRES D'ÉNERGIE N'EST PAS DU TOUT LA MÊME QUE CE QU'ELLE ÉTAIT EN 1970.

CECI EST VRAI EN PARTICULIER POUR L'INDUSTRIE DE L'ÉNERGIE ÉOLIENNE. LA TECHNOLOGIE ÉOLIENNE A BEAUCOUP PROGRESSÉ AU COURS DES DERNIÈRES ANNÉES, ET UN SAVOIR-FAIRE DE GRANDE QUALITÉ S'EST DÉVELOPPÉ TANT AU SEIN DES CENTRES DE RECHERCHE QU'AU SEIN DES ENTREPRISES MANUFACTURIÈRES ET DE GÉNIE-CONSEILS. LE DÉVELOPPEMENT DES ÉOLIENNES AU QUÉBEC SE COMPARE AVANTAGEUSEMENT À CE QUI S'EST FAIT DANS LES AUTRES PAYS, TANT AU NIVEAU DE LA DÉMONSTRATION QUE DE LA FABRICATION, DE MÊME QU'EN CE QUI CONCERNE LA RECHERCHE ET LE DÉVELOPPEMENT AU NIVEAU DES TECHNOLOGIES ET DES OUTILS D'ANALYSE.

LES PETITES ÉOLIENNES FONT PRÉSENTEMENT LA DÉMONSTRATION DE LEUR DURABILITÉ ET FIABILITÉ. LES PROGRÈS SONT DE PLUS EN PLUS RAPIDES À MESURE QUE LES ENTREPRISES MANUFACTURIÈRES PRENNENT DE L'EXPANSION SUR DE NOUVEAUX MARCHÉS.

EN CE QUI CONCERNE LES GRANDES ÉOLIENNES, NOUS EN SOMMES ENCORE AU STADE DU DÉVELOPPEMENT DES PROTOTYPES, MAIS LES EXPÉRIENCES ACTUELLES PERMETTENT L'ACQUISITION DU SAVOIR-FAIRE PAR LES ENTREPRISES DE SERVICE ET D'INGÉNIERIE.

Au niveau commercial, l'industrie québécoise de l'énergie éolienne est peut-être un peu jeune et son marché quelque peu limité. Cependant, les espoirs de développement sont assez prometteurs, particulièrement dans certains créneaux spécialisés comme le marché des régions isolées non rattachées au réseau d'électricité, ainsi que dans le marché de l'exportation. Ainsi, l'énergie solaire a réussi à assurer son développement par la conquête des marchés d'exportation.

Nous croyons que malgré la baisse récente des prix du pétrole, les pays consommateurs doivent poursuivre leurs efforts en vue de se doter d'une "police d'assurance" pour faire face à toute éventualité. Le développement des économies d'énergie et des énergies nouvelles est un des éléments principaux de cette police d'assurance et constitue à plus long terme une action absolument essentielle. Les politiques du Gouvernement font une plus large place maintenant à l'entreprise privée et sont moins directives.

Le Ministre de l'Energie et des Ressources disait d'ailleurs à cet égard, lors de sa conférence à l'A.Q.M.E. tout récemment, et je cite, "Je tiens à spécifier que nous ne devons pas nous permettre de perdre nos acquis, nos connaissances et l'expertise acquise, nous devons voir par dessus les monts et vallées de la conjoncture actuelle et réaliser qu'en ce temps d'accalmie, c'est précisément la bonne période pour consolider nos forces, pour diffuser nos technologies parmi nos entreprises et pour nous préparer au prochain coup dur".

Le Ministre de l'Energie se disait également personnellement en faveur de la continuation de l'entente fédérale-provinciale, ou de la signature d'une nouvelle entente de trois ans avec le gouvernement fédéral afin d'assurer une meilleure coordination et la mise en commun des ressources financières pour promouvoir les activités en matière d'économies d'énergie et d'énergies nouvelles.

LE MINISTÈRE DE L'ENERGIE ET DES RESSOURCES EST CONSCIENT DU FAIT QUE LES INDUSTRIES DES ÉCONOMIES D'ÉNERGIE ET DES ÉNERGIES NOUVELLES ONT ENCORE BEAUCOUP DE POTENTIELS DE CROISSANCE ET QU'IL EST IMPORTANT DE LES AIDER À TRAVERSER UNE PÉRIODE PEUT-ÊTRE MOINS ENTHOUSIASMANTE, DUE À LA BAISSE DES PRIX DU PÉTROLE, POUR QU'ELLES DONNENT LEUR PLEIN RENDEMENT.

CECI EST VRAI, A FORTIORI, POUR L'INDUSTRIE ÉOLIENNE QUI N'A PEUT-ÊTRE PAS ATTEINT LE MÊME STADE DE DÉVELOPPEMENT QUE LES AUTRES FORMES D'ÉNERGIE.

NOUS ESPÉRONS QU'UNE ASSOCIATION COMME LA VÔTRE NOUS AIDERA À MIEUX DÉFINIR, DANS LES MOIS QUI VIENNENT, LA NATURE ET LE TYPE D'INTERVENTION REQUIS DES GOUVERNEMENTS POUR LES AIDER À ATTEINDRE CE PLEIN DÉVELOPPEMENT.

NOUS CROYONS QUE CE TYPE D'ASSOCIATION EST UN INSTRUMENT ESSENTIEL À L'ÉTABLISSEMENT D'UNE CONCERTATION SUR LES ACTIONS À PRENDRE POUR ATTEINDRE NOS OBJECTIFS, ET C'EST EN CE SENS QUE LE MINISTÈRE DE L'ENERGIE ET DES RESSOURCES SOUTIENT DIRECTEMENT VOTRE ASSOCIATION.

LA PRÉSENTE CONFÉRENCE SURVIENT À POINT NOMMÉ POUR NOUS GUIDER DANS LA RÉALISATION DE NOTRE ACTION EN CETTE MATIÈRE. JE TIENS À VOUS REMERCIER DE L'OCCASION QUI M'A ÉTÉ DONNÉE DE VOUS ADRESSER LA PAROLE, ET JE VOUS SOUHAITE UNE BONNE SOIRÉE.

DEMONSTRATION PROGRAMS

FT. SEVERN WIND/DIESEL PROJECT UPDATE

Per Drewes & Duncan Hume

The Community

Fort Severn is about as remote a community in Ontario as one could find. Any further north and one would be in Manitoba or end up with wet feet from the waters of Hudson Bay. The small native community of 300 people is approximately 800 kilometres from the nearest road. Most materials are delivered by aircraft. It is also about the same distance from Ontario Hydro's distribution system and represents one of about twenty small native communities in which the utility operates small diesel generating stations.

Fort Severn's diesel generating station went into service last Christmas. It represents a new approach to station design and features three different sizes of generators: 85 kW, 125 kW, and 175 kW. A programmable controller selects the operating diesel generator to best match the electrical demand of the community in an attempt to maximize fuel efficiency of the station.

Delivering fuel for these diesel generating plants by aircraft results in very expensive electricity. The estimated fuel cost for the Fort Severn project was 40 cents per kilowatt-hour, more than ten times the average fuel cost on Hydro's main grid.

In addition to high fuel costs, Fort Severn experiences some of the highest winds in Ontario. Annual averages of 5.8 m/sec will not excite the imagination of most wind energy entrepreneurs, but for the Province of Ontario they represent the windiest site available.

These are the two conditions, very high fuel costs and relatively high wind speeds, which resulted in Fort Severn being selected as the site of Ontario's first "large scale" operational wind turbine.

The Challenge

There are now over 13,000 wind turbines in California, including many installed by Howden. What is the interest in the Fort Severn machine?

The Fort Severn project is unique in many aspects. Aside from the problems of remoteness, harsh environment and limited local manpower availability, the Fort Severn wind/diesel installation probably represents the highest penetration of wind power on an electrical grid anywhere in the world. In California, there are legal requirements which limit renewable sources, be it wind or solar, to ten percent of the capacity on a system. To any interconnected 60 kW wind turbine, the utility represents a very stable system. The 60 kW wind turbine in Fort Severn will, at times, run in parallel with an 85 kW diesel generator. The governor on the diesel is required to set the pace so to speak, for the complete Fort Severn electrical generating system. Given the fluctuations of the wind component, maintaining power quality can be quite a challenge.

Ontario Hydro, working with the Ontrio Ministry of Energy, The Canadian Electrical Association and Energy, Mines and Resources, has gained considerable experience with control aspects of wind energy at the Sudbury wind test site. The Fort Severn project represents the first practical application of this experience. Hopefully, the features of this unique wind/diesel system will find similar applications in other remote small communities in Canada and throughout the world.

Meeting the Challenge

The challenge has two components. The first is to design a machine that is stable enough to provide more than 50% of the power to the system while operating in parallel with a diesel generator; the second is to place a relatively large and sophisticated machine in a remote location without the construction equipment and infrastructure and that would be available at locations that have road access.

Today, I am going to concentrate on the installation of the machine at Fort Severn, this challenge has already been met. At next year's CANWEA Conference we will have had considerable running experience and I hope to speak about the joys and pitfalls of using a synchronous wind turbine generator to achieve high penetrations into remote small community electricity distribution systems.

Installation

Our Original schedule called for the foundations to be poured in the Summer of 1985 with the wind turbine being manufactured and tested prior to installation at site during the Summer of 1986. Despite not being awarded the contract until June 1985, we elected to stick to that original schedule and we proceeded with great dispatch to prepare 40 tons of cement, 20 tons of rebar, 3 tons of insulation and fencing, 2 cement mixers, and a variety of miscellaneous equipment for shipment to Fort Severn on a barge from Moosonee that was originally scheduled to depart on July 26th. All the material arrived in Moosonee in time for the planned departure date then waited for four weeks for the ice to clear from Hudson's Bay. Luckily, the weather was kind to us in Fort Severn that September and the foundations were poured and the compound completed by early October.

During this time, the detail design of the HWP60 wind turbine was being undertaken in Glasgow, by Christmas 1985 the machine was configured as a synchronous generator using a dump load for speed control and load limiting. A programmable controller is used to oversee the machine operations. New material specifications were prepared for all load bearing components to ensure that the machine would be suitable for operation at the low temperatures prevalent during the Fort Severn winter; heaters have been included in all the oil pans and in other strategic locations. A decision not to use spring activated blade tip brakes because of uncertain operation at low temperatures resulted in the incorporation of a hydraulic power pack to provide the power necessary to operate the new low speed shaft brake.

Manufacture of the machine was completed during the Spring of 1986 and extensive factory testing was undertaken prior to the erection of the machine at Penicuik on the Pentland hills, South of Edinburgh. The wind turbine was put through its paces and performed as expected, optimizations and modifications were made to the machine and to the computer software during the two months spent on the Scottish hillside. At Penicuik the HWP60 was operated in parallel with a 150 kW diesel.

The testing was determined to be complete in May and the machine was dismantled and crated for shipping to Fort Severn. The route was to Toronto by boat, forwarded by rail to Moosonee and then by barge to Fort Severn. This time there was no significant delay to the barge departure and the machine was unloaded at Fort Severn in early August.

There were many days of rain and the first snow was on the ground the morning of September 8/86. By early October the site was ready for the Hydro crew to run in the interconnecting cabling and only the blades remained to be installed.

Acknowledgement

The Fort Severn Project is being funded by the Ontario Ministry of Energy; Ministry of Natural Resources through the Remote Community Demonstration Program; Canadian Electrical Association and Ontario Hydro. The project is managed by Ontario Hydro and the wind turbine system has been designed and supplied by Howden Group Canada. All site work has been undertaken by the Fort Severn Indian Band under the supervision of Howden.

PROJECT EOLE UPDATE

G.H. Beausoleil and J. Plante
Shawinigan Consultants Inc.
A Division of Lavalin Inc.

INTRODUCTION

Project Eole is a vertical axis wind turbine generator (VAWTG) of the Darrieus type under construction in Cap-Chat, Québec.

Originally funded by Hydro-Québec and the National Research Council of Canada, the property of Eole has been transferred in May 1986 to Shawinigan Consultants Inc., a Divison of Lavalin Inc., which had been retained by Hydro-Québec as engineering consultants, responsible for the overall design. Lavalin agreed to complete the construction of the wind turbine, to operate it as an electric power generating station and also to use the facilities for scientific research.

The VAWTG has five major subsystems which are the turbine rotor, the rotor support system and the mechanical, electrical and instrumentation systems. These are briefly described and the reasons for the selection of specific design options are given.

The present status of the project is reviewed. The installation as designed is illustrated pictorially in Fig. 1.

MAJOR SUBSYSTEMS

Turbine Rotor

The primary components of the rotor are the central column, the blades and the horizontal struts. Basic structural details are provided in Fig. 2.

The central column is 96 m long and 5 m in diameter and consists of 6 sections of rolled and welded sheet steel having a thickness of 12 mm. The sections are joined by bolted spliced joints. Conical end sections, fabricated from 40 mm steel, reduce the diameter to a flange which is bolted to a matching flange on the shaft. These end sections also include provisions for attachment of the blades by bolted connections. Similar provisions are included at 20 percent and 80 percent of rotor height for bolted connection of the horizontal struts.

A damping device is mounted inside the column above the upper horizontal strut. It consists of a suspended 18 tonne weight having its horizontal movement relative to the column controlled by a spring and damper system. The damper system is optimally tuned to minimise loads and stresses caused by in-plane and out-of-plane forces acting to deflect the two-blade rotor from the vertical.

An access door is provided at the bottom of the column and a second door at the top of the column provides access to the upper bearing platform via an external ladder. A ladder system with staging platforms at 5.5 m intervals and a 500 kg capacity electrically-operated manlift are provided inside the column. There are equipment rooms at the top and bottom of the column.

The blades have a chord of 2.4 m and maximum thickness of 0.43 m and consist of a fabricated box-section in 6 mm steel with internal stiffeners and with fibreglass nose and tail sections. The fibreglass sections incorporate an aluminium mesh layer which is bonded to the box section to protect internal hydraulic piping and electrical cables and to minimise blade damage in the event of a lightning strike.

The blades are constructed in straight 5.7 m long sections and are connected together by either in-line or 4 degree offset bolted spliced joints. The troposkein shape is approximated as a straight length from each end of the central column connected by an arc of a circle in the equatorial region. The 8 degree angled connections are to achieve the arc. The blades are connected to the column by diagonal struts.

Aerodynamic brakes have been included for additional security against runaway. These are located in the tail section of the three blade sections closest to the equator and replace the fibreglass section used elsewhere. The brakes are hydraulically-operated from a redundant pump/accumulator system located in the central column and connected by high pressure lines running inside the blades. The two normal airfoil surfaces of the brake are effectively hinged at the tail tip and so are assisted in the opening direction by the aerodynamic drag. The actuators apply pressure to open and close.

Blade section details are given in Fig. 3.

The horizontal struts are structural stiffening members to assist in supporting the blades. Fibreglass cowlings are provided for the outer third of their length to reduce the aerodynamic drag. A walkway is provided on the strut with an access door in the central column for inspection of the strut-blade connection which is the most highly stressed area on the rotor. The strut connections to both column and blades are rigid to allow the distribution of transmitted torque between blades and struts.

Rotor Support System

The rotor support system consists of the structure supporting the bottom rotor bearing and the guy-cable system attached to the upper bearing platform to keep the rotor vertical.

The bottom bearing support structure consists of six reinforced concrete legs which serve the additional function of providing the frame for the housing of the power train equipment. This structure must not only take the weight of the rotor but also the additional vertical loading imposed by the guy-cable system. This amounts to a normal total vertical loading of 6000 kN. For design purposes, the design takes into account a uniform 50 mm ice coating which produces a total vertical loading of 9000 kN as the maximum with the VAWTG stationary.

The top bearing support system consists of six, 76 mm diameter, bridge-strand guy cables spaced at 60 degrees. The number was fixed at six as the least cost minimum which would allow a cable to be removed and replaced without dismantling the rotor.

The nominal guy angle to the horizontal is 35 degrees which is the optimum in terms of horizontal rigidity.

The guy cables are attached at the top to the upper bearing platform and at ground level to anchors whose design is dependent on the particular soil conditions.

Intermediate masts, at a radial distance of 90 m, are provided to support the guy cables. Their function is to reduce the unsupported cable length and thereby increase the natural frequency above the excitation frequency levels expected in operation.

To protect the VAWTG against lightning strikes and minimise damage, lightning rods are fitted to the upper bearing platform to protect the local instrumentation and electrical services.

The most probable ground path is through the guy cables and these are directly bonded at the top to the upper bearing platform and at the bottom to the VAWTG ground mat to bypass the cable end-connections.

The alternative path to ground is through the rotor. Slipring assemblies provide a low impedance bypass for the upper bearing and the lower bearing and pivot; the lower assembly being directly connected to the ground mat. As a further precaution, a grounding brush is provided on the generator shaft to bypass the generator.

The overall VAWTG ground mat interconnects the guy cables at the anchor points, the guy cable anti-resonance masts, the perimeter fence and the rotor support structure reinforcing steel in addition to providing the ground for the main electrical equipment.

Mechanical System

The mechanical system (see Fig. 4) includes the rotor top and bottom bearings, the rotor pivot, the mechanical brake and the flexible coupling.

The bottom bearing comprises spherical roller thrust and guide bearings supporting an alloy steel integrally flanged shaft within a cast steel housing. The assembly is oil-lubricated by an automatic dual pumping system. Triple seals and a collection system minimise the possibility of leakage on to the brake and generator.

The top bearing is similar in construction, but smaller since there is no torque transmission requirement, and is grease lubricated.

The rotor pivot is interposed between the bottom bearing and the rotor and allows for displacement of the rotor from the vertical. It consists of an elastomer thrust pad and a flexible link coupling for transmitting the torque. No lubrication is required and there is no backlash in the coupling. A vertical displacement of 3 degrees in any direction is allowable compared with less than one degree expected.

Maintenance provisions include hydraulic jacking systems to allow the upper bearing and the pivot/lower bearing to be removed without the need to dismantle the rotor.

The mechanical brake consists of two 5 m diameter, 65 mm thick discs each fitted with three equally-spaced calipers mounted on brackets which are bolted to the underside of the concrete building. The total nominal braking torque is 5400 kN i.e. about twice rated torque. The brake is normally used to stop from about 20 percent of rated speed in which case only one disc is used. However, in an emergency, the brake is capable of full stopping duty from overspeed.

The brake is pneumatically operated to release and spring applied. With the VAWTG parked, all calipers are applied. This arrangement supersedes the parking lock specified in the project definition.

The flexible coupling is of the resilient type and consists of two ductile iron halves with cast lugs to accept the 16 pre-loaded elastomeric cylindrical elements which transmit the torque between the two coupling halves. Independent friction damping is included between the outer surfaces of the lugs and the outer cover to help control large amplitude, low frequency oscillations. No lubrication is required and the elements can be examined or replaced with the coupling in place.

The coupling caters for axial and parallel misalignment in addition to torsional flexibility and damping. An extension shaft connects the flexible coupling to the generator shaft.

Electrical System

The basic electrical system is shown schematically in Fig. 5. The grid interface is a conventional outdoor substation. All other electrical equipment is housed in the rotor support building except the emergency braking resistors which are outdoors adjacent to the building.

The electrical system consists of a 4.14 MVA, 3.7 MW, 3.6 kV, 19.24 Hz, 162 pole synchronous generator which is directly-driven by the turbine and connected to the Hydro-Québec grid through a static frequency changer (SFC) and 6.5 MVA, 4.16/69 kV step-up transformer. The SFC converts the generator output to d.c. and then inverts it to a.c. at grid frequency. This asyrchronous tie between generator and grid allows the turbine to be operated over a speed range to maximise energy production. The generator static excitation system is fed from the grid, through the 750 kVA auxiliary services transformer, and is controlled so that the generated voltage is proportional to rotational speed. The generator thereby operates at constant flux and the d.c. current in the SFC is approximately proportional to the electrical torque.

The SFC can transfer power in both directions so that the generator can be driven as a motor to start the turbine which is not reliably self-starting.

The generator-side converter is operated at full inversion for motoring and full rectification for generating. The grid-side converter is used to control the power transfer and hence the rotational speed. If the power transferred exceeds the turbine output the deficit is taken from the rotational energy of the turbine rotor causing it to decelerate. If the turbine is developing more power than the SFC transfers then it will accelerate.

Filters are included in the speed control loop to make it insensitive to the two per revolution oscillations in torque produced by the two-bladed turbine rotor. The resulting torque and hence output power oscillation amplitude for Eole will be less than one percent compared with up to 30 percent or higher for similar VAWTGs with conventional power trains.

Fifth and seventh harmonic filters are provided on the grid side of the SFC to absorb the harmonic currents generated by the SFC. Power factor correction capacitors are also provided to correct the grid side power factor to unity at half load. The power factor at full load will be about 0.9 leading.

In the event of a grid outage, braking load is provided by a resistor bank and generator excitation is provided by a battery. For other faults which prevent power transfer to the grid, the braking resistor is used in conjunction with the normal excitation system, if available. In normal operation, the SFC is used to electrodynamically brake the turbine.

The auxiliary services transformer supplies the building heating and ventilation system, building and exterior lighting and power supplies to the turbine rotor via sliprings at the lower end of the generator shaft and a 600 V cable running inside the shaft and drive train components to the lower equipment room in the rotor column. It also provides services to the remote control room and administration building. These services are additional to the main electrical system services which include a 10 kVA uninterruptible power supply (UPS) to ensure essential supplies in the event of loss of the grid and allow a safe shutdown of the VAWTG.

Control of the SFC determines the operation of the VAWTG and is carried out at two levels. The first direct level is by a micro-processor based system incorporated in the SFC which controls both thyristor converters. Closed-loop control consists of an inner loop, which sets the d.c. current level in accordance with a reference value, and an outer loop which provides the current reference signal and controls the VAWTG rotational speed.

The inner loop has fast response and includes safety features for protecting the SFC and generator.

The outer loop is relatively slow-acting since its dominant time constant is the accelerating time constant of the VAWTG rotating system, whose main components are the rotor and generator. If the rotating system is considered as a single rigid mass, this time constant is 32 s; 31 s of which is attributable to the rotor. The outer loop includes the torque ripple filters.

The outer loop speed reference signal and VAWTG operating mode commands are supplied to the SFC by the second level of control which comprises redundant programmable controllers (PCs) with on-line bumpless transfer.

All essential inputs are monitored at this level and these can be summarised as:

a) Wind speed

- The mean value determines satisfactory conditions for VAWTG startup.
- The instantaneous and mean values determine high-wind cut-out when the VAWTG is stopped to prevent both electrical and structural overload.
- The mean value is used to compute the speed control reference level during variable speed operation.

b) Rotational speed

- This provides the reset signal for the speed control loop.
- To detect overspeed conditions and initiate the appropriate VAWTG shutdown mode.

c) Equipment monitoring

All components critical to safe operation of the VAWTG are monitored and, if conditions deviate from the acceptable range, the VAWTG is shut down. Some of the most critical are:

- Rotor bearing temperature and vibration.
- Generator temperature and vibration.
- Rotor stresses.
- Guy cable tension.

Signals not provided directly by the main electrical equipment are supplied by the data acquisition system described under instrumentation.

The PC is equipped to carry out all control functions necessary to operate the VAWTG. In addition to full control of the electrical equipment, it also controls the aerodynamic and mechanical braking systems.

The equipment layout in the building is shown in Fig. 6. In ultimate unattended operation, the local control room, item 8 in Fig. 6, will be used primarily for maintenance purposes. However, for the startup and evaluation stage of the project, a remote control room is provided.

The VAWTG/operator interface in the control room consists of two colour video display units (VDUs), one of which is for alarm display only, and a keyboard to allow the operator to access any part of the system for information, select automatic or manual over-ride operation and any one of three VAWTG control modes. A second keyboard allows changes to be made to level settings or control sequences. The interface communicates with the PC and vice versa via an information management unit (IMU).

An independent microcomputer is provided for off-line program development and de-bugging before downloading to the PC.

A printer and 3-pen recorder are provided to produce hardcopy.

Instrumentation

The instrumentation system can be segregated into rotor-based and ground-based subsystems.

Rotor-based instrumentation sensors include:

- Strain gauges, accelerometers and ice detectors on each blade.
- Wind speed and direction, ambient temperature and bearing temperature on the upper bearing platform.
- Aerodynamic brake open and closed status and drive train torque.

The instrumentation system also transmits the signal to deploy and close the aerodynamic brakes.

A 2 kVA UPS in the rotor lower equipment room ensures that essential supplies are available for orderly shutdown under emergency conditions.

Communication between the data acquisition equipment in the control room and the lower equipment room in the rotor column is over a fibre-optic link which includes a rotary joint (optical slipring). The rotary joint is incorporated with the conventional power supply sliprings into an assembly mounted on the lower end of the generator shaft. Two additional sliprings are included in this assembly for a hardwired circuit which allows the operator to directly deploy the aerodynamic brakes.

The optical link employs wavelength multiplexing/de-multiplexing with multi-channel data transmission. The overall data transmission system is based on pulse code modulation (PCM). This is converted to binary for the central processor by a decommutator in the control room.

Ground-based instrumentation sensors are hardwired and include:

- An anemometer on a nearby meteorological tower to provide a backup wind speed signal.

- Strain gauges for guy cable tension measurement.
- Rotational speed. Two sensors: one above and one below the flexible coupling.
- Lower rotor bearing temperature and vibration.
- Mechanical brake disc surface temperature.

Over 120 data channels are sequentially scanned at rates up to 5,000 samples per second which provides an adequate number of samples per cycle for the highest signal frequencies of interest and for the possible addition of extra channels in the future.

Signal conditioning amplifiers provide energising supplies required by the transducers and adjustments are available for voltage, gain or other changes in the field.

Data essential to the operation of the VAWTG are routed to the PC and vice versa over an RS232C serial link. A second RS232C link is provided for telephone line communication with a remote dispatch centre to transmit VAWTG status information and to provide the remote operator with control of the VAWTG during unattended operation.

An IEEE488 serial link provides an interface with another computer and will be used during the VAWTG evaluation period for on-site processing of data.

Long term data storage is provided in the form of a 9 track tape. A 31 Mbyte hard disc continuously stores up to 30 minutes of data and then overwrites it during the next 30 minutes to provide short term data storage.

A printer allows hardcopy to be made from tape or disc and a VDU and keyboard provide the interface between the operator and central processor.

PROJECT STATUS

The status of the project, as of mid-October 1986, is that the civil works, comprising rotor support structure, guy and mast anchors, ground mat, boundary fence and access roads, are complete.

The main electrical equipment and mechanical drive train components, from the lower rotor bearing to the generator, have been installed and pre-commissioned.

Erection of the rotor and commissioning of the VAWTG were planned for Spring 1986 and Fall 1986, respectively, but due to delays in the fabrication and delivery, the erection activities did not start until mid-June 1986 when a stiff-leg derrick with hoist was installed near the rotor support structure.

This was followed at the beginning of August by the installation of the pivot and the supporting structure equipped with hydraulic jacks on which the rotor was to be erected prior to lowering it onto the pivot. The column was then erected in five sections which were bolted in place and supported by temporary guy wires; this operation, including the installation of the top platform with the upper bearing, the jacking system and the monorail, took place from August to the third week of September.

Beginning in September, one blade assembly was prepared on the ground and then lifted in place: first the upper horizontal and diagonal struts, then the lower horizontal and diagonal struts and finally the central portion of the blade. This last operation was completed in the second week of October.

The rotor erection is continuing and should be completed by mid-November with the tensioning of the six guy cables. The completion of all work prior to commissioning activities is scheduled for mid-December. Starting in January 1987, the VAWTG will go through the commissioning tests followed by an evaluation period leading eventually to commercial operation.

CONCLUSIONS

From the work carried out so far on the design, fabrication and installation, it has been learned that:

- Even though some of the components and subsystems are in the forefront of technology, they are within the capability of Canadian expertise.
- The manufacture of large VAWTGs has excellent potential for the development and expansion of Canadian industry.

When Project Eole is operational in 1987, it will provide:

- A demonstration of operational reliability and availability.
- Experience of environmental impact.
- An opportunity to evaluate the design and performance.

At the end of the evaluation period, it is anticipated that Project Eole will:

- Confirm the technical feasibility of large VAWTGs.
- Verify the analytical techniques used in the design.
- Encourage and enhance the prospects of building large VAWTGs in Canada for the domestic and international markets.

ACKNOWLEDGEMENT

The authors wish to thank the other members of the Project Eole design team, specifically H. Benjannet, A. Galin, H.G. Ford, H. Bratcoveanu, B. Richards and S. Chawla for their help in ensuring the accuracy of the finer details presented in this paper.

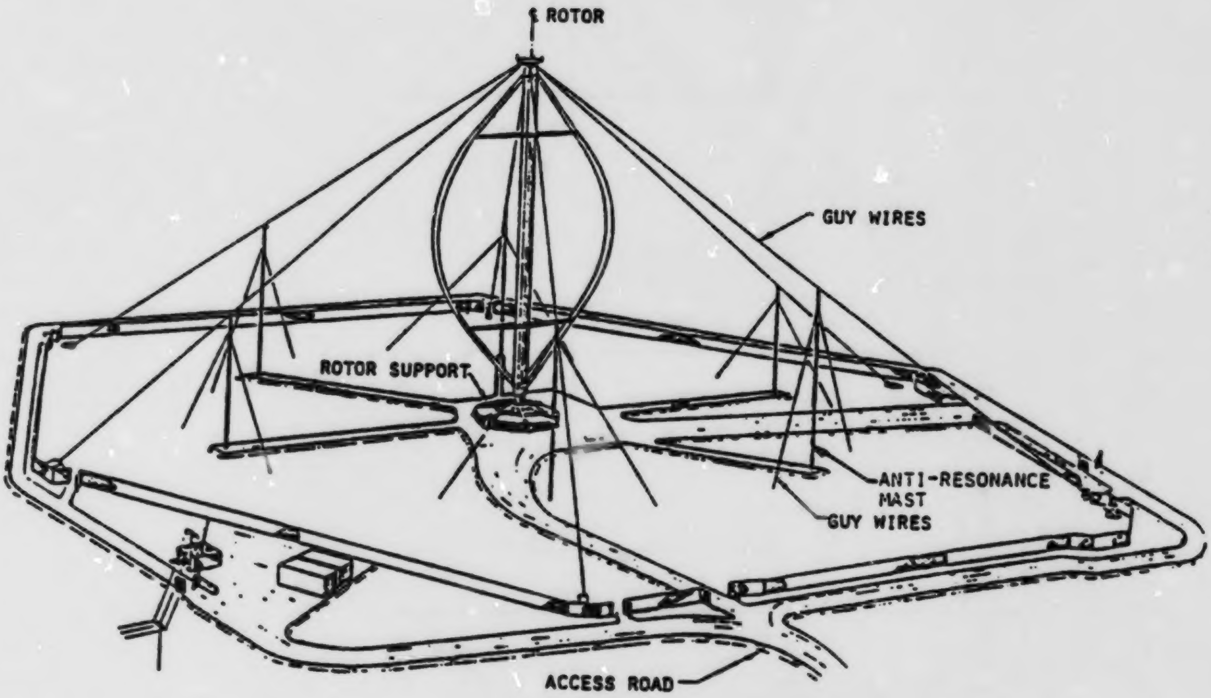

℄ ROTOR
GUY WIRES
ROTOR SUPPORT
ANTI-RESONANCE MAST
GUY WIRES
ACCESS ROAD

Fig. 1 - Project EOLE Design Configuration.

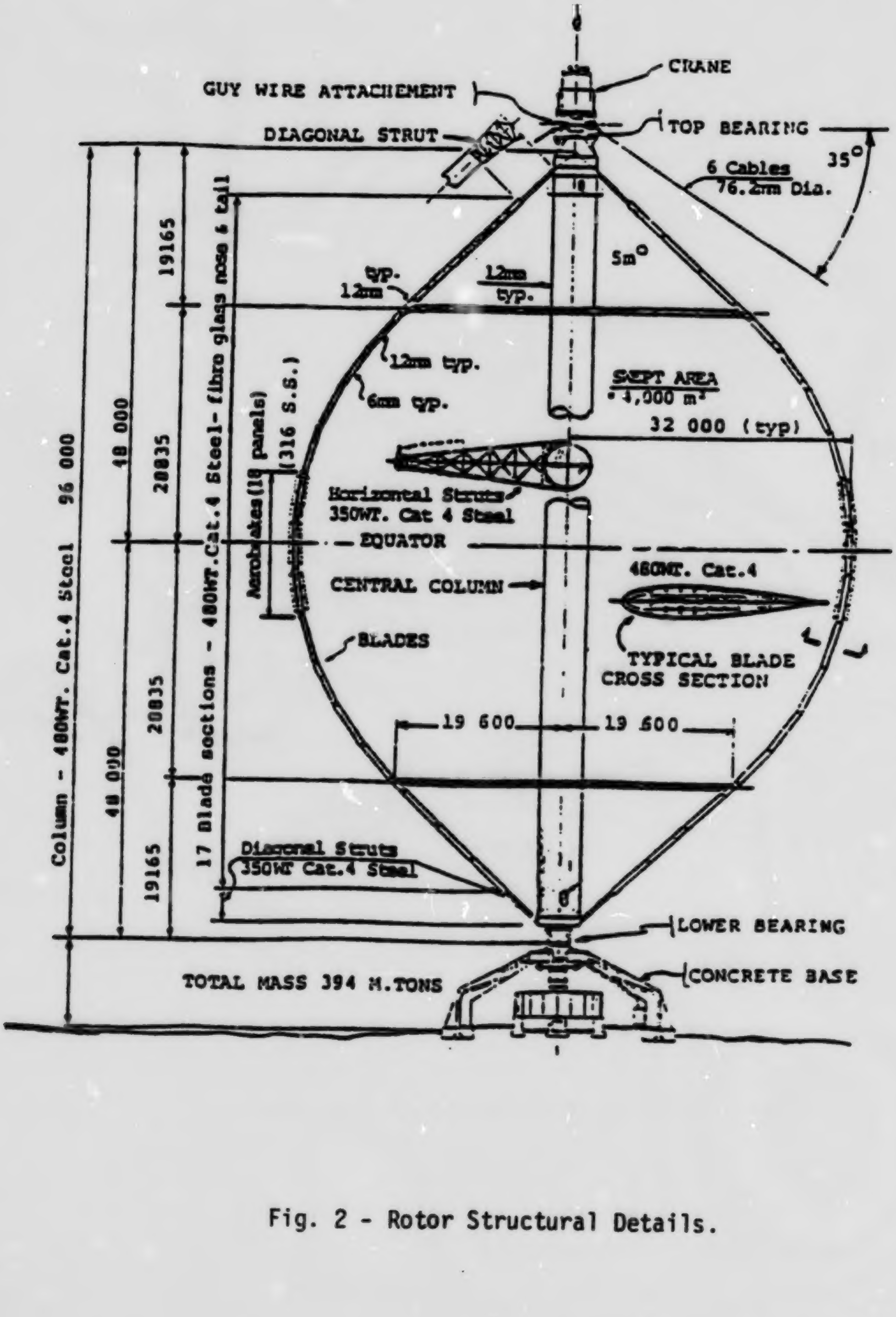
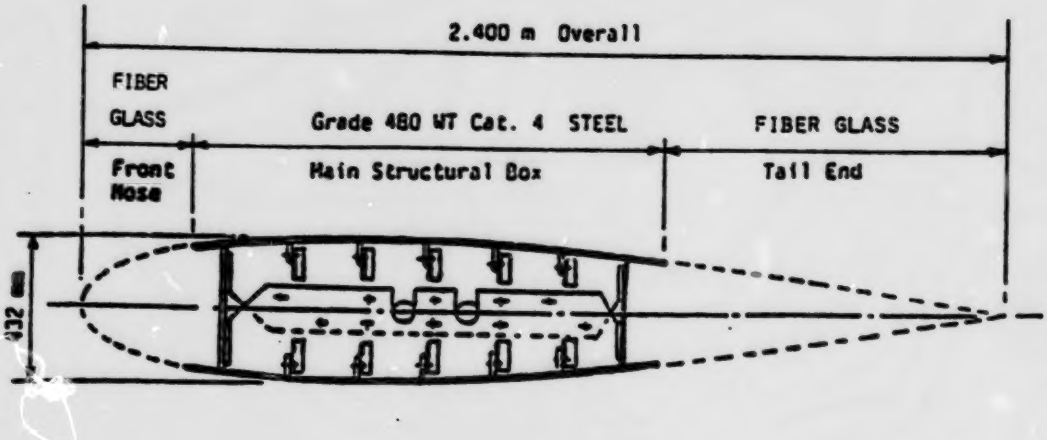
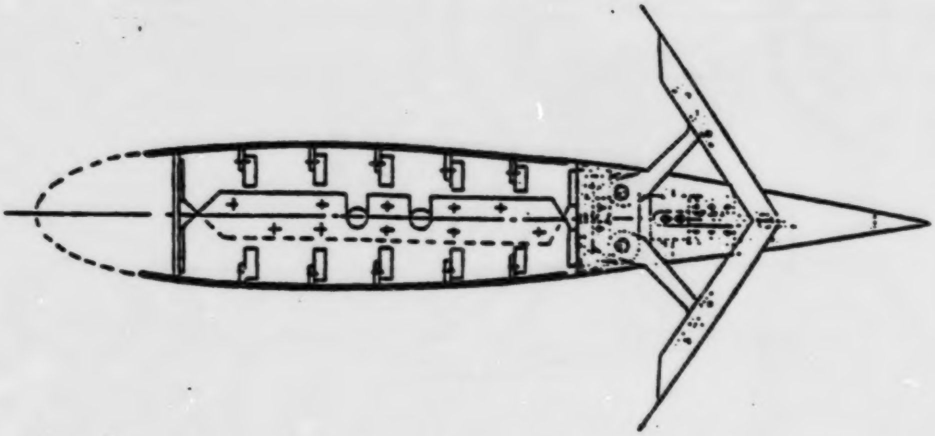

CRANE
GUY WIRE ATTACHEMENT
TOP BEARING
DIAGONAL STRUT
6 Cables
76.2mm Dia.
35°
5m°
typ.
12mm
12mm
typ.
12mm typ.
6mm typ.
SWEPT AREA
= 4,000 m²
32 000 (typ)
Horizontal Struts
350WT. Cat 4 Steel
EQUATOR
CENTRAL COLUMN
480WT. Cat.4
TYPICAL BLADE
CROSS SECTION
BLADES
19 600
19 600
Diagonal Struts
350WT Cat.4 Steel
LOWER BEARING
CONCRETE BASE
TOTAL MASS 394 M.TONS
Column - 480WT. Cat.4 Steel 96 000
48 000
48 000
19165
20835
20835
19165
17 Blade sections - 480WT.Cat.4 Steel- fibre glass nose & tail
Aerobrakes(18 panels)
(316 S.S.)

Fig. 2 - Rotor Structural Details.


2.400 m Overall
FIBER GLASS
Grade 480 WT Cat. 4 STEEL
FIBER GLASS
Front Nose
Main Structural Box
Tail End
432 mm

a) - Normal Blade Section.



b) - Blade Section Including Aerodynamic Brake.

Fig. 3 - Rotor Blade Sections.

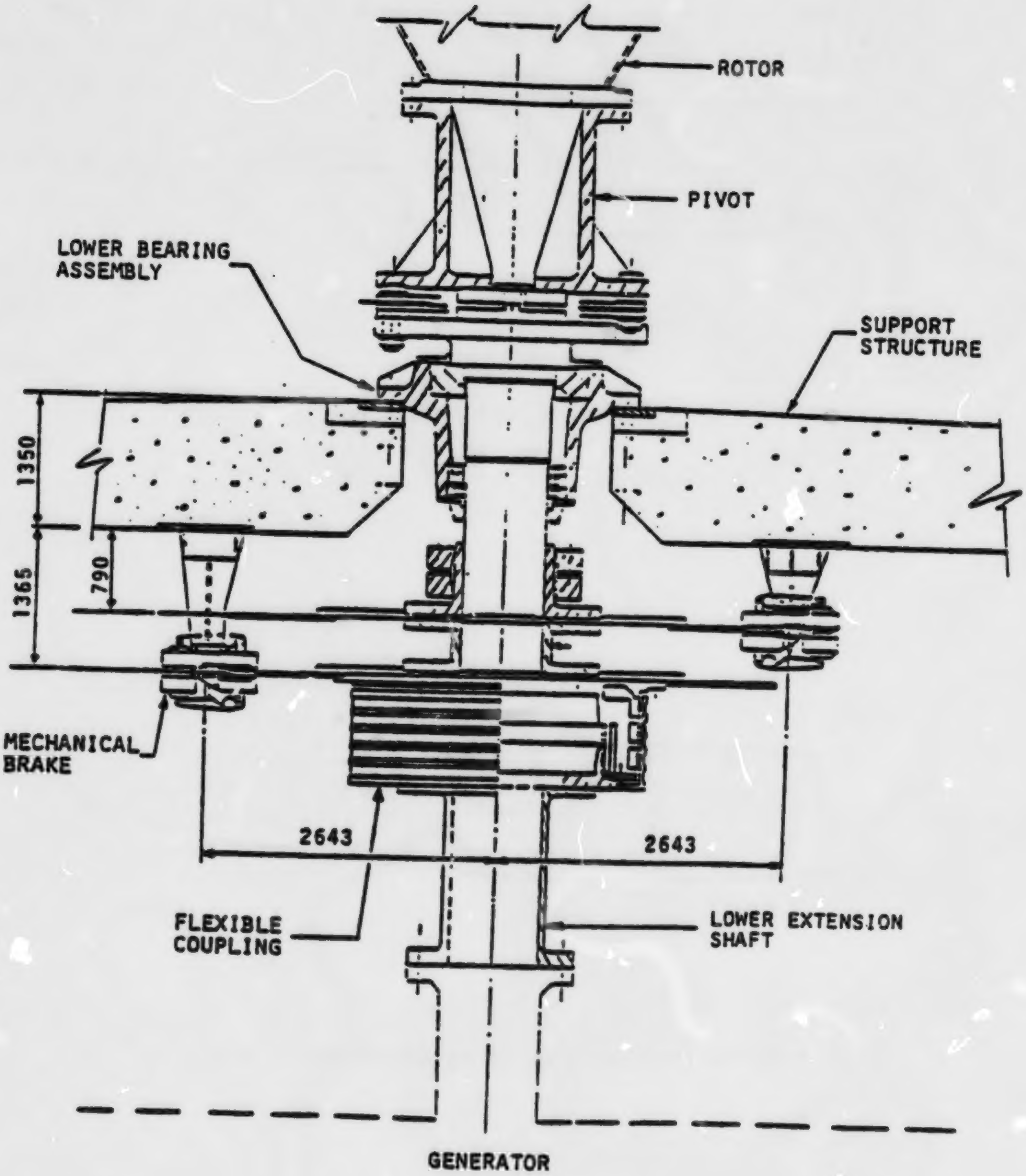

ROTOR
PIVOT
LOWER BEARING ASSEMBLY
SUPPORT STRUCTURE
1350
1365
790
MECHANICAL BRAKE
2643
2643
FLEXIBLE COUPLING
LOWER EXTENSION SHAFT
GENERATOR

Fig. 4 - Mechanical Drive Train Arrangement.

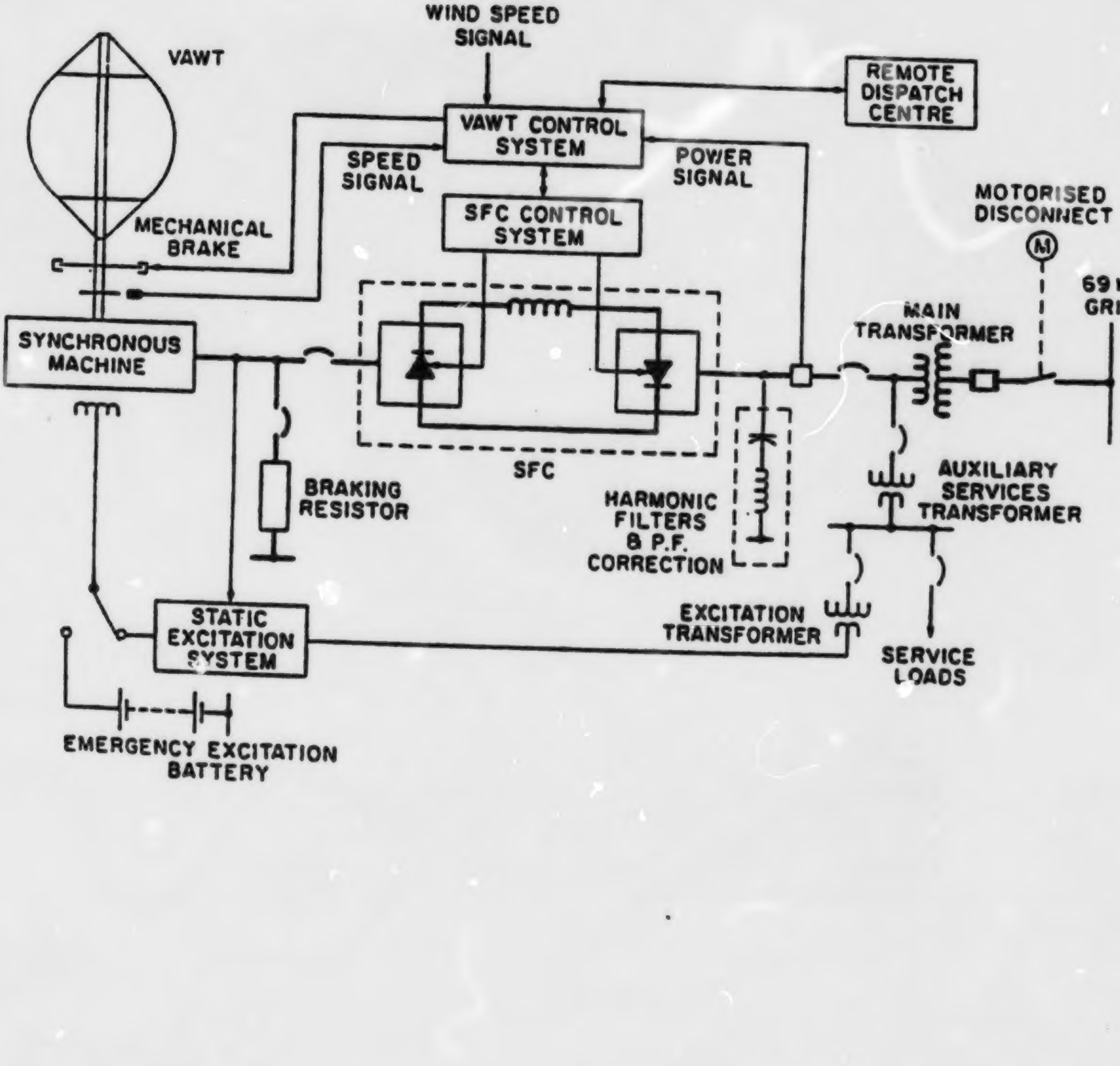
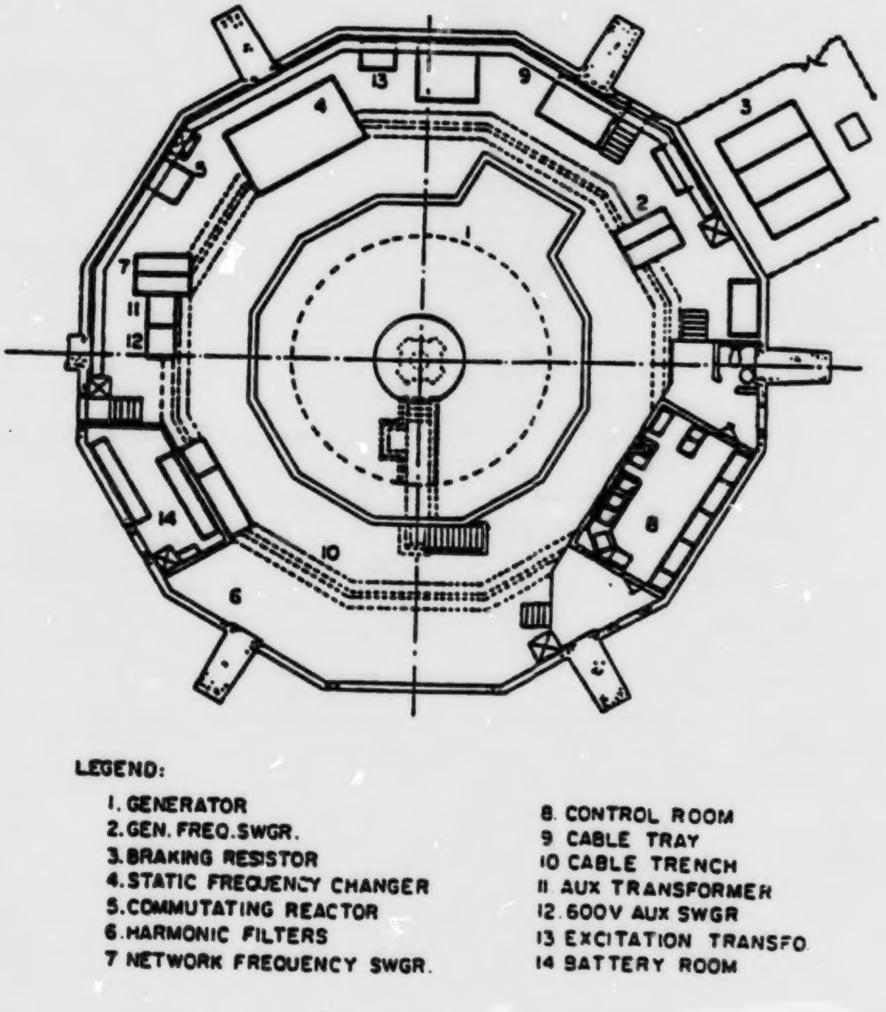

WIND SPEED SIGNAL
VAWT
REMOTE DISPATCH CENTRE
VAWT CONTROL SYSTEM
SPEED SIGNAL
POWER SIGNAL
SFC CONTROL SYSTEM
MECHANICAL BRAKE
MOTORISED DISCONNECT
M
69 kV GRID
MAIN TRANSFORMER
SYNCHRONOUS MACHINE
SFC
BRAKING RESISTOR
HARMONIC FILTERS & P.F. CORRECTION
AUXILIARY SERVICES TRANSFORMER
EXCITATION TRANSFORMER
STATIC EXCITATION SYSTEM
SERVICE LOADS
EMERGENCY EXCITATION BATTERY

Fig. 5 - Basic Electrical Scheme.



LEGEND:

1. GENERATOR
2. GEN. FREQ. SWGR.
3. BRAKING RESISTOR
4. STATIC FREQUENCY CHANGER
5. COMMUTATING REACTOR
6. HARMONIC FILTERS
7. NETWORK FREQUENCY SWGR.
8. CONTROL ROOM
9. CABLE TRAY
10. CABLE TRENCH
11. AUX TRANSFORMER
12. 600V AUX SWGR
13. EXCITATION TRANSFO.
14. BATTERY ROOM

Fig. 6 - Rotor Support Building Electrical Equipment Layout.

WIND/DIESEL POTENTIAL FOR REMOTE POWER SYSTEMS:
TECHNICO-ECONOMIC ASPECTS

R. Reid and B. Saulnier
Institut de recherche d'Hydro-Québec
1800 montée Ste-Julie, Varennes, Québec J0L 2P0

INTRODUCTION

Diesel-generator units supply electricity to 135000 people in 290 communities in Canada, the demand mix being 44% residential and 56% commercial. The total installed diesel power capacity of 350 MW delivers about 530 GWh (1) annually. This amounts to an average capacity factor of 17.3% and much higher costs of electricity production than those associated with the bulk power system . At the present time there are 800 remote diesel-generator units in operation in Canada (2).

Wind turbines are expected to find their first economically viable application in remote communities, where electricity costs and wind regime are high. Optimization of the wind diesel (W/D) mix will naturally depend on the following factors (3-5):

- geography and local wind regime
- local load profile on different time scales
- economics and reliability of the power sources
- existing power plants and distribution system
- requirements for supply reliability
- control strategy and priorities for wind energy acceptance

The first part of this paper discusses the various technical aspects of W/D coupling and fuel savings in remote systems. Different wind-integration scenarios are analysed briefly and a high-wind-penetration W/D scenario is proposed which, technically, has the potential to accept all the energy

---

Canadian Wind Energy Association Annual Meeting, 26-28 October 1986, Québec City, Qc.

produced by the wind without any need for storage. This concept will be analytically and experimentally verified in the coming year. An economic analysis based on this scenario is presented in the second part of the paper.

1. WIND/DIESEL COUPLING

Coupling together two power-producing units such as a diesel-generator and an aerogenerator (AG) to satisfy the varying demand of an isolated community is not simple. All the operating requirements of each major element must be taken into account if the final system is to have any chance of success. There are two basic requirements on the final system:

1) The cost of transforming a diesel plant into an efficient and reliable W/D plant must be covered by the fuel savings realized over the lifetime of the system (4).

2) The quality and quantity of the power supply must be at least equivalent to what the community was used to.

The first requirement suggests control priorities that allow all the energy produced by the AG to serve useful purposes in the community. In principle, this will ensure the greatest fuel savings. Note that the corresponding fuel cost savings will be a weighted function of the displaced diesel-generator (overall yearly efficiency: ≈ 30%) plus water/space heating (excess wind power replacing fuel burners at 65% efficiency) of any building in the community.

The second requirement calls for a control system that will ensure any mismatch between W/D power production and demand is absorbed either by some form of storage (too much wind energy production or large load disconnection) or by increasing the diesel generator power output (drop in wind energy production or large load reconnection). This will keep the voltage, frequency and power quality acceptable and guarantee supply reliability.

CHARACTERISTICS OF DEMAND VS WIND AND DIESEL POWER

Demand vs Wind

The demand and AG output spectra exhibit similar frequency trends: minute-by-minute, hourly, daily and seasonal variations are present for both. However, since demand is largely fashioned by community habits, it is easier to predict in terms of frequency and amplitude. If wind energy production on a power system is often compared to a negative load, it must be made clear that it is a random load at all times and that its effects on the system stability and on fuel savings will be strongly dependent on the control system used, especially at high penetration rates.

Demand vs Diesel

A diesel-generator unit is a simple and flexible machine which adapts rapidly to load variations and acts so as to keep the power system frequency and voltage within an acceptable range. It is a good load follower. However, unfortunately, it is very inefficient in converting fuel to electricity. Furthermore, when operated at a lower rating, its specific fuel consumption increases as the load decreases, which hikes the average annual price of electricity delivered by such equipment.

If the load factor (average/peak load) of the power system is low, as is often the case in remote communities, the diesel capacity factor can only be lower. The diesel unit may be forced to operate at a low loading level for a large percentage of the time if minimum diesel loading level (MDLL) and spinning reserve operating criteria are applicable. Alternatively, if the spinning reserve criteria is not enforced, the diesel unit may be subjected to a high number of start/stop cycles. In both cases the result is a very high energy production cost in terms of fuel and maintenance (frequent repairs) and poor long-term reliability. In locations where electricity must be available at all times, units of different capacities are used to feed the load, the nominal rating of each unit being of the order of the MDLL of a larger unit. Reliability is then very good but the overall capacity factor is generally worse and the electricity costs are still high.

Diesel vs Wind

Compared to the diesel-generator, an AG is a poor producer of power on demand. However, combining the energy-oriented AG with the power-oriented diesel unit, a more reliable scheme with a lower mean energy cost than entirely diesel schemes emerges.

Diesel units and AGs are modular, which means that W/D mix can be varied and/or adapted by adding or replacing commercial units of different energy/power ratings. If economic studies indicate a high level of wind penetration (150% for example) at a particular site, it is interesting to observe that a group of smaller-size AGs would, in periods of wind, produce varying power such that their average/peak value, measured over a few seconds interval, will very likely be higher than what could be achieved by a single large unit (7). This is due to the real three-dimensional wind field which, over a large geographical area, tends to smooth out variations in the output of any single machine. In this case, some base power capacity could even be attributed to wind power.

FACTORS AFFECTING FUEL SAVINGS IN A W/D SYSTEM

Depending on the machine characteristics (electrical, mechanical, transient, protection and control), the load profile and the selected control priorities, integration of AGs into an existing diesel power plant can introduce or add to the operating problems of the diesels:

1) large number of start/stop cycles;

2) larger proportion of running time at low loading levels;

3) mismatch between wind and demand, which imposes a higher load-following burden on the diesel system. The diesel unit sees a net load equal to the demand minus the wind power (8). This net load is inherently more random than the demand itself, especially at high wind-penetration levels in turbulent wind conditions and with a small number of windmills. Control strategy is

critical in this case, if the design objective is 100% acceptance of wind energy;

4) reduced power stability.

If these problems are not addressed properly, the fuel savings attributed to the AGs will be reduced. Awareness of the potential problems has led to the development of four basic scenarios of W/D mix that are recognized as being technically feasible (3, 4, 6, 10-14, 17).

1) Negative Load Scenario

Wind power is seen as a negative load. It should not be allowed to force the diesel to operate under its minimum load level if system stability is to be maintained. The maximum penetration of wind power in this scenario is limited to 30-40%.

Hour-by-hour simulations have shown (9) that at 30% wind penetration, about 25% of the wind energy must be rejected because of system constraints. In the case studied, the minimum spinning-reserve criterion for the diesel power was responsible for rejecting any excess energy from the wind.

This scenario does not require any change in the diesel controls.

2) Independent Scenario

In this scenario (10, 11), AGs and diesel units are separated, each feeding their own power distribution system. High penetration and significant fuel savings are possible with this scheme. Frequency-controlled heating elements distributed in the community buildings are used for maintaining the AG operating speed once priority loads (lighting, motors, appliances) are satisfied. The diesel unit can be shut down whenever the average wind power exceeds the priority-load demand, an advantage which could significantly reduce maintenance costs in windy areas.

The control system for this scenario is straightforward and requires few modifications but the need for a double distribution system and may be prohibitive in some areas.

3) Cooperative Scenario

A high level of wind penetration with 100% energy acceptance, should be possible with some form of electrical storage (14) for absorbing higher-frequency mismatch and minimizing diesel operation at low load levels. This scenario should result in greater fuel savings and a reduction in operating hours at the MDLL and improve the reliability and power quality. However, it has one drawback: electrical storage (batteries and DC/AC converters) is often unsuitable for W/D plants, which call for high charge/discharge rates for short-term frequency maintenance. In fact, even with very high fuel prices, a storage capacity of more than a few hours at average load cannot be economically justified (3).

No long-term performance of the cooperative scenario has yet been demonstrated.

It should be pointed out that a multiple diesel backup system in a carefully designed control strategy can obviate the need for storage, at the expense of an increase in fuel consumption (6). The use of a thyristor-controlled dump load can also replace storage although at the expense of a lower, albeit acceptable, power quality (13, 15). These two possibilities can also be combined to replace storage (17).

4) No-Storage High-Penetration W/D Scenario

The system that seems to offer the best cost-benefit and technical feasibility at the present time is a hybrid solution combining scenarios 2 and 3 (see Figure 1).

The control algorithm favors 100% wind-energy acceptance (maximum all-load fuel savings). Priority loads are defined as existing electrical appliances, excluding water or space heating. When wind power is insufficient to fulfill demand, the diesel maintains the frequency ($f \leq 60$ Hz). When wind power is, on the average, equal or higher than demand, higher-frequency mismatches are dealt with by means of small frequency-controlled heating loads and a large, infinitely variable, building heating load. The value of the fuel savings reflects the mix of a high fuel value for priority loads and a lower fuel value of the heating loads. Active load management, together with a multiple diesel backup and a suitable priority decision tree, could fulfil the objectives of the W/D scheme at high wind-penetration levels.

These three elements would replace the storage of scenario 3. Storm front and wind gusts are taken into account in the diesel regulator modifications and in the control algorithm.

The dynamics of the different elements in this scenario (diesel, vertical-axis wind turbine and control system) will be evaluated experimentally at IREQ's AG testing facility (16) which will be converted to be able to test in different operating conditions of wind and typical load variations in order to identify:

1) the critical regulator parameters for dynamic stability in all operating conditions and acceptable power quality in relation to the mechanical and electrical characteristics of AGs and diesel units;

2) optimum sizing of the distributed dissipative load mix;

3) validity of different control priorities;

4) scenario limitations.

2. ECONOMIC ANALYSIS

The study of these scenarios and especially the experiments conducted by WTG on Cuttyhunk Island in 1977 (12), at IREQ in 1978 (24) and more recently at ECN in the Netherlands (13), led the authors to believe that the most economical system to supply wind energy to Northern Québec villages is the no-storage high-penetration W/D scenario. The following economic analysis is therefore based on the latter, with its underlying assumption that the control and regulation system will allow wind energy to be used primarily to supply the primary electrical demand at a value equal to the diesel generator set cost of fuel while the surplus will supply part of the heating demand of the village at a value equal to the cost of fuel heating.

DEFINITIONS

For the purpose of this analysis, penetration is defined as the ratio of the installed capacity of the wind power to the local peak demand. The net present value (NPV) is the present value of future returns discounted at the firm's cost of capital minus the cost of the initial investment. The internal rate of return (IRR) is the interest rate that equates the present value of the expected future net cash flows or receipts to the initial outlay; it is the interest rate which makes NPV = 0. Finally, the payback period is the number of years required to return the original investment.

The IRR assumes that cash flows are automatically reinvested at the IRR, whereas NPV assumes that cash flows are reinvested at the firm's cost of capital. NPV is more conservative and will therefore be the primary parameter in this analysis.

METHODOLOGY

Starting from a demand probability curve typical of a Northern Québec village (Figure 2) and the power curve of a 65-kW Danish wind turbine (Figure 3), the energy accepted (and rejected) by the system (Figure 4) and the displacement of the oil used for electricity generation (Figure 5) are calculated for different penetration levels and for a range of wind speeds.

For two Northern Québec villages, depending on the choice of sites, the wind speed was estimated at between 21 and 28 km/h (5.8 to 7.8 m/s) (18). As the conditions reported in Reference 18 are probably representative of most villages in that area, the three wind speeds selected for the present study are 5.8, 6.8 and 7.8 m/s.

The energy accepted by the system is worth the cost of the fuel that would have been used to produce the same electricity. The value of wind energy used for heating is calculated using an oil heating efficiency of 6.75 kWh/L[1].

Hydro-Québec purchases fuel from the Fédération des Coopératives du Nouveau-Québec for five villages, and from an oil company for the other nine. The cost of diesel fuel for Northern Québec has been forecast for these two sources (referred to as COOP and SHELL respectively) and is presented in Table 1 (19). Besides the reference scenario, Table 1 also shows a reference - 25% and a reference + 25% scenarios, the 25% is referring to the international cost of petroleum. Table 1 shows the cost landed at the powerhouses.

The share of the total electrical production of Northern Quebec used by the two sources is presented in Table 2 (20), while the electrical production efficiencies of the diesel used in the villages served by each fuel supplier is presented in Table 3 (21).

Table 4 presents the weighted costs of fuel for both electricity generation and heating, forecasted for the years 1986 to 2010. This table, calculated from data in Tables 1 to 3, represents the cost of fuel for an average village having the weighted diesel generator sets efficiency and the weighted fuel source of the Northern Québec villages. The base year selected is 1990, since it is unlikely that such a program be implemented before then. All the calculations are therefore in 1990 dollars.

Based on a project study done by Hydro-Québec for a 3-MW windfarm for the Magdalen Islands (22), the installed cost of the wind turbines for Northern Québec has been estimated at three times the ex-factory cost of the wind turbine. The ex-factory cost is estimated at $78 400 in 1986 for the cold-temperature version of the 65-kW Danish wind turbine. The installed cost inflated to 1990 becomes $288 072.

---

[1] Hydro-Québec, Internal Markets, Agenda 1986. Net value of equivalent weighted fuel.

The annual maintenance cost has been estimated at 3% of the installed cost, based on the Magdalen Islands wind farm study (22) adjusted for northern conditions.

The other parameters of the economic analysis are a cost of capital of 11.5% (19), an inflation rate of 5.2% (23) and a useful life of 20 years.

Table 5 shows an example of the calculations for one of the cases studied. Starting from year 0 (1990), an annual mean wind speed of 7.8 m/s and a given year-0 penetration level of 100% in the example, the revenues are calculated from the energy accepted by the system (Figure 4) at the cost of electricity (Table 4) plus the energy rejected (Figure 4) at the cost of heating (Table 4). The maintenance cost is deducted from the revenue and the result is multiplied by the discounting factor to obtain the present value in 1990 dollars. The process is repeated for the 20 years of useful life. The NPV, IRR and the payback period are calculated from the cumulative present value.

As can be seen from Table 5, for a given penetration in year 0, the forecasted growth in demand (Table 6) (20) results in reduced penetration and increased acceptance of wind energy by the system in subsequent years.

RESULTS

The results (total NPV, NPV per turbine, IRR and payback period) are presented in Figures 6 through 15. Figures 7 to 9 and 13 to 15 show the sensitivity to fuel prices for the NPV and the payback period respectively.

According to Figure 6, optimum penetration would be around 100% for wind speeds of 6.8 and 7.8 m/s. For a wind speed of 5.8 m/s, the wind turbine just about breaks even at a penetration lower than 50%. The NPV at optimum penetration for a wind speed of 7.8 m/s reaches approximately 50% of the installed cost of the wind turbines.

On the basis of NPV/turbine (Figure 10) at a penetration of 50%, the NPV reaches about 75% of the installed cost for a wind speed of 7.8 m/s and about 40% for a wind speed of 6.8 m/s.

The IRR (Figure 11) can be as high as 22%. At optimal penetration, it varies from 14% to 18% for wind speeds of 6.8 and 7.8 m/s respectively.

At low penetration (50%), the payback period (Figure 12) can be as low as 9 years for a wind speed of 7.8 m/s and up to 12 years for a wind speed of 6.8 m/s. It slightly exceeds 20 years for a wind speed of 5.8 m/s. At optimum penetration, it is about 12 and 15 years for wind speeds of 7.8 and 6.8 m/s respectively.

The fuel price sensitivity analysis (Figures 7 to 9) shows that the NPV remains positive (project is profitable) if the oil price drops by 25% for both the 6.8 and 7.8 m/s wind speeds. However, the optimum penetration drops from 100% to 50% for a 6.8-m/s wind speed. If the oil price increases by 25%, the NPV becomes positive for a 50% penetration at a wind speed of 5.8 m/s. Both the 6.8- and the 7.8-m/s cases are more profitable (higher NPVs) and the optimum penetration for the latter case is now 150%.

The effects of longer or shorter payback periods with lower or higher oil prices can be seen in Figures 13 to 15.

Figure 5 shows that for optimum penetration (100%) for wind speeds of 6.8 and 7.8 m/s respectively, 54% and 63% of the fuel used to produce electricity can be displaced by wind energy.

DISCUSSION

The NPV per turbine, IRR and payback periods figures seem to indicate that the higher the penetration, the less profitable a wind turbine will be. This is because the lower the penetration, the higher the portion of energy sold at the cost of electricity rather than at the cost of heating. Figure 6 (total NPV) shows that even if the first 50% is more profitable, the second 50% is also profitable. Even if diminishing returns are obtained, it is still profitable to add wind turbines up to optimum penetration.

Before such a project is implemented, much more detailed calculations are needed. Each village must be considered separately for the choice of sites (wind regime), cost of fuel and electrical demand. For example, wind energy is likely to be very profitable for COOP-supplied villages because of higher fuel prices. The average village with the reference + 25% scenario is about equivalent to the COOP village with the reference - 25% scenario. For these COOP villages, the optimum penetration for a wind speed of 7.8 m/s is 200% and the NPV is equal to the installed cost, figure 16.

The financing aspect also deserves further investigation. Despite the fact that Hydro-Québec does not pay income tax, advantage can be taken of the accelerated depreciation through lease-purchase, the lessor absorbing the tax credits and leasing the installation to Hydro-Québec. A quick calculation of this effect is shown on figure 16. Adding the effect of leasing to a COOP village gives the curve COOP + LP in figure 16, where for wind speed of 7.8 m/s, the optimal penetration is above 300% and the NPV is around 150% of the installed cost.

For sake of simplicity, the calculations were based on a specific wind turbine. Recent developments tend to show that slightly larger wind turbines are more cost-effective. For villages where the fuel cost, winds and size of demand dictated a high installed capacity, larger wind turbines might be a better choice, provided enough turbines are installed in a given village to result in a more stable wind power in the presence of gusts.

CONCLUSION

After a review of the present state of wind/diesel technology, the study indicates that a no-storage high-penetration scheme appears technically and economically feasible while maintaining an acceptable quality of supply. An economic analysis of the potential of wind energy has shown that, with the present control scenario and forecast fuel prices, an average wind speed of 6.8 m/s and an optimum (100%) penetration, some 9 MW of wind turbines could be profitably installed in Northern Québec villages for a NPV of around 8 000 000$.

On the basis of this study, analytical studies and experimental developments of the control and regulation system are currently being initiated. If the work goes as planned, the successful and profitable application of this high-penetration wind energy scheme in Northern Québec should soon become a reality.

REFERENCES

1. M. Tennis, "Wind Energy Applications on Isolated Diesel Systems," Report 139G267, Canadian Electrical Association, Sept. 1983.

2. J.G. Keller, "Status of Research in Wind/Diesel Systems in Canada," National Research Council of Canada, 19...

3. D.G. Infield et al., "Review of Diesel Strategies," IEE Proceedings, Vol. 130, Pt.A. No. 9, Dec. 1983.

4. H.A. Madsen, P. Lundsager, "The Wind Diesel Program at RisØ National Laboratory, Status, 1985," Risø No. 2537, Sept. 1985.

5. A. Tsitovits, L.L. Freris, "Dynamics of an Isolated Power System Supplied from Diesel and Wind," 5th Annual Conference of the British Wind Energy Association, U.K., 23-25 March 1983.

6. D.G. Infield, "Small-Scale Wind/Diesel Systems for Electricity Generation in Isolated Communities," 5th Annual Conference of the British Wind Energy Association, U.K., 23-25 March 1983.

7. P. Caselitz, G. Hackenberg, W. Kleinkauf, "Short-Time Behaviour of Diesel Generators when Integrated with Wind Energy Converters," Proceedings of the European Wind Energy Conference, Hamburg, Germany, October 1984.

8. M.P. Schroeder, N.A. Henein, "State-of-the-Art Assessment on the Development and Engineering Analysis of Hybrid Wind/Diesel Systems," Wind Power '85 Proceedings, San Francisco, August 1985.

9. G. Desrochers, "Mesure de l'apport effectif d'une nouvelle unité de production et son incidence sur la fiabilité du réseau," IREQ-2470, December 1981.

10. W.M. Somerville, J. Puddy, "Wind Power on Lundy Island," 5 th Annual British Wind Energy Association Conference, Reading University, U.K., March 1983.

11. W.G. Stevenson, W.M. Somerville, "The Fair Isle Wind Power System," 5th Annual British Wind Energy Association Conference, Reading University, U.K, March 1983.

12. W.R. Lowstuter Jr., "Wind Supplies Much of Cuttyhunk Island's Electric Power," Electrical Consultant, Sept/Oct. 1979.

13. J.A.N. de Bonte et al., "Two Dutch Autonomous Wind Diesel Systems," Wind Power 1985 Proceedings, San Francisco, U.S.A., 27-30 August 1985.

14. Mechron Energy Ltd., "An Analysis of Cycle Charge and Wind Turbine Hybrid Power Plants for Remote Community Applications," NRC+M-WE-026, March 1985.

15. G.A. Phillips, J.W. Walton, F.J. Kornbrust, "Progress in Self-Commutated Inverters for Fuel Cells and Batteries," United Technologies Corporation, HP-110, February 1978.

16. B. Dubé et al., "Validation of Digital Simulation of an Aerogenerator with a Wound-Rotor Asynchronous Generator and Slip-Power Recovery System," submitted to PICA 1987, Montreal.

17. "Fort Severn Wind Diesel Hybrid," Howden Group Canada Ltd., 19...

18. "Éolienne, Ungava, Municipalités de Quaqtaq et d'Ivujivik, Évaluation Préliminaire," Hydro-Québec Report No. 08710-RA-83/29, February 1984.

19. P. Cormier, F. Dupuis, "Prévision du prix des produits pétroliers sur les territoires desservis par les réseaux isolés d'Hydro-Québec," Hydro-Québec, July 1986.

20. H. Gautron, "Prévisions de la demande, 1985-2010, pour 14 villages de l'Ungava," Hydro-Québec, 15 April 1986.

21. F. Gagnon, "Programme d'équipement 1985-1990, Centrales Diesels," Hydro-Québec, 20 September 1985.

22. Matthieu P. Lavallée, "Parc d'éoliennes aux îles de la Madeleine," Report No. 08710-578-325, Hydro-Québec, November 1985.

23. General Planning, Hydro-Québec, 1986.

24. B. Saulnier & D. Marois, "IREQ Wind Energy Conversion System", Proceedings of the 1982 annual meeting of SESCI, ENERGEX 82, 23-29 August 1982. Regina,Saskatchewan.

TABLE I

Forecasted costs of petroleum, Northern Quebec

(¢/litre)

Year	Reference Scenario		Reference - 25%		Reference + 25%	
	COOP	SHELL	COOP	SHELL	COOP	SHELL
1986	67.6	53.4	67.6	53.4	67.6	53.4
1987	66.3	51.5	61.0	46.2	71.6	56.8
1988	65.9	50.3	61.2	45.6	70.6	54.9
1989	69.1	52.7	64.1	47.8	74.0	57.6
1990	72.5	55.3	67.4	50.2	77.6	60.4
1991	76.1	58.0	70.8	52.6	81.4	63.3
1992	80.3	61.3	74.6	55.6	86.0	66.9
1993	84.8	64.7	78.7	58.7	90.8	70.8
1994	89.5	68.4	83.0	62.0	95.9	74.8
1995	94.4	72.2	87.6	65.4	101.3	79.1
1996	99.7	76.3	92.3	68.9	107.0	83.7
1997	105.5	80.9	97.6	73.0	113.5	89.0
1998	111.6	85.8	103.1	77.3	120.5	94.6
1999	118.2	91.0	109.0	81.9	127.9	100.7
2000	125.1	96.5	115.3	86.7	135.7	107.1
2001	132.4	102.4	121.9	91.8	143.0	112.9
2002	140.3	108.6	128.9	97.3	151.6	120.0
2003	148.5	115.3	136.3	103.0	160.7	127.5
2004	157.3	122.3	144.2	109.2	170.4	135.4
2005	166.6	129.8	152.6	115.7	180.7	143.9
2006	176.5	137.8	161.4	122.6	191.7	152.9
2007	185.9	144.9	169.8	129.0	201.7	160.9
2008	195.4	152.5	178.6	135.7	212.1	169.3
2009	205.5	160.4	187.9	142.8	223.2	178.1
2010	216.2	168.8	197.7	150.2	234.8	187.3

Source: Reference 19

TABLE 2

Forecasted share of total northern Quebec electricity production for villages having fuel supplied by the COOP or by SHELL

Year	COOP		SHELL	
	MWh	%	MWh	%
1986	7594	28.1	19418	71.9
1990	9033	28.2	22990	71.8
1995	10418	27.6	27358	72.4
2000	11739	26.4	32672	73.6
2005	13195	26.2	37155	73.8
2010	14634	26.0	41758	74.0

Source: Reference 20

TABLE 3

Average electrical efficiencies of Diesels in Northern Quebec

(kWh/litre)

Year	COOP villages	SHELL villages
1986	2.97	3.04
1990	3.02	3.14
1995	3.07	3.19
2000	3.10	3.24

Source: Reference 21

TABLE 4

Weighted Fuel Costs

Electricity Generation and Heating

($/MWh)

Year	Reference Scenario		Reference - 25%		Reference + 25%	
	electricity	heating	electricity	heating	electricity	heating
1986	190.26	85.02	190.26	85.02	190.26	85.02
1987	183.13	82.46	176.26	74.61	200.54	90.31
1988	178.97	81.01	163.62	74.05	194.09	87.87
1989	186.17	84.90	170.20	77.60	202.05	92.16
1990	194.15	89.11	177.73	81.56	210.57	96.67
1991	202.96	93.46	185.72	85.50	219.98	101.31
1992	213.63	98.70	195.39	90.25	231.64	107.03
1993	224.65	104.13	205.43	95.20	244.02	113.13
1994	236.53	109.99	216.10	100.47	256.88	119.47
1995	248.73	116.04	227.19	105.97	270.60	126.26
1996	262.72	122.57	238.57	111.51	285.48	133.49
1997	276.73	129.80	251.84	118.10	302.17	141.76
1998	292.03	137.43	265.33	124.84	319.76	150.51
1999	308.65	145.57	280.04	132.05	339.04	159.94
2000	325.78	154.15	295.14	139.63	358.85	169.85
2001	345.37	163.44	312.35	147.77	378.25	179.03
2002	366.06	173.24	330.38	156.32	401.58	190.09
2003	388.26	183.75	349.61	165.42	426.36	201.83
2004	411.52	194.77	369.93	175.04	452.43	214.18
2005	436.46	206.58	392.51	185.73	480.49	227.47
2006	463.05	219.17	415.67	196.69	510.29	241.58
2007	486.85	230.44	437.19	206.89	536.81	254.15
2008	512.23	242.51	459.88	217.63	564.73	267.36
2009	538.70	255.00	483.74	228.93	593.97	281.22
2010	566.86	268.33	508.86	240.82	624.71	295.78

Source: calculated from tables 1,2 & 3

TABLE 5

Calculations for : annual mean v= 7.8 m/s, 100 % penetration

Year	% Pen	% E acc	Rev	Maint	R-M	A F	PV	Cum P
1990	100.0	64.3	40383	8642	31741	1.0000	31741	31741
1991	95.0	67.0	43005	9091	33914	.8969	30416	62157
1992	92.5	68.0	45590	9564	36026	.8044	28978	91135
1993	89.9	69.5	48436	10061	38375	.7214	27684	118819
1994	87.5	70.2	51254	10585	40669	.6470	26312	145131
1995	85.1	71.8	54089	11135	42954	.5803	24925	170056
1996	82.3	73.0	57971	11714	46257	.5204	24073	194129
1997	79.9	74.5	61679	12323	49356	.4667	23036	217165
1998	77.2	75.8	65637	12964	53673	.4186	22049	239214
1999	74.8	77.3	70023	13638	56385	.3754	21169	260383
2000	72.1	78.5	74469	14347	60122	.3367	20243	280626
2001	69.5	79.8	79558	15093	64465	.3020	19468	300094
2002	68.1	80.5	84673	15878	68795	.2708	18631	318725
2003	66.6	81.8	90493	16704	73790	.2429	17924	336649
2004	65.1	82.7	96418	17573	78846	.2178	17176	353825
2005	63.6	83.8	102914	18486	84428	.1954	16496	370321
2006	62.1	84.5	109624	19448	90176	.1752	15801	386122
2007	60.8	85.0	115589	20459	95130	.1572	14950	401072
2008	59.5	86.0	122312	21522	100790	.1409	14206	415278
2009	58.1	87.0	129363	22642	106721	.1264	13491	428769

Cost (-)	288072
NPV/Turbine	140697
Total NPV	140697
Pay Back Period	11.4 years
IRR	18.6 %

% Pen = % Penetration = Wind Turbine(s) Installed Capacity/Peak Demand

% E acc = % Energy accepted by the Network

Rev. = annual Revenues

R-M = Revenues - Maintenance

PV = Present Value = (R-M)x AF

Maint = Maintenance

AF = Actualization Factor

Cum PV = Cumulative PV

TABLE 6

Forecasted demand for 14 villages in Northern Quebec

Year	Gross Electricity Production		Heating Demand (Fuel)	
	MWh	% increase over previous year	kL	% increase over previous year
1986	27012	-	15116	-
1987	28089	3.99	15324	1.38
1988	29324	4.40	15526	1.32
1989	30597	4.34	15739	1.37
1990	32023	4.66	15962	1.42
1991	33707	5.26	16230	1.68
1992	34623	2.72	16548	1.96
1993	35606	2.84	16905	2.16
1994	36602	2.80	17266	2.14
1995	37646	2.85	17665	2.31
1996	38898	3.33	18158	2.79
1997	40092	3.07	18443	1.57
1998	41478	3.46	18808	1.98
1999	42828	3.25	19131	1.72
2000	44411	3.70	19556	2.22
2001	46091	3.78	19982	2.18
2002	47039	2.06	20417	2.18
2003	48108	2.27	20865	2.19
2004	49184	2.24	21336	2.26
2005	50378	2.43	21845	2.39
2006	51554	2.33	22382	2.46
2007	52675	2.17	22823	1.97
2008	53862	2.25	23306	2.12
2009	55110	2.32	23757	1.94
2010	56402	2.34	24352	2.50

Source: Reference 20

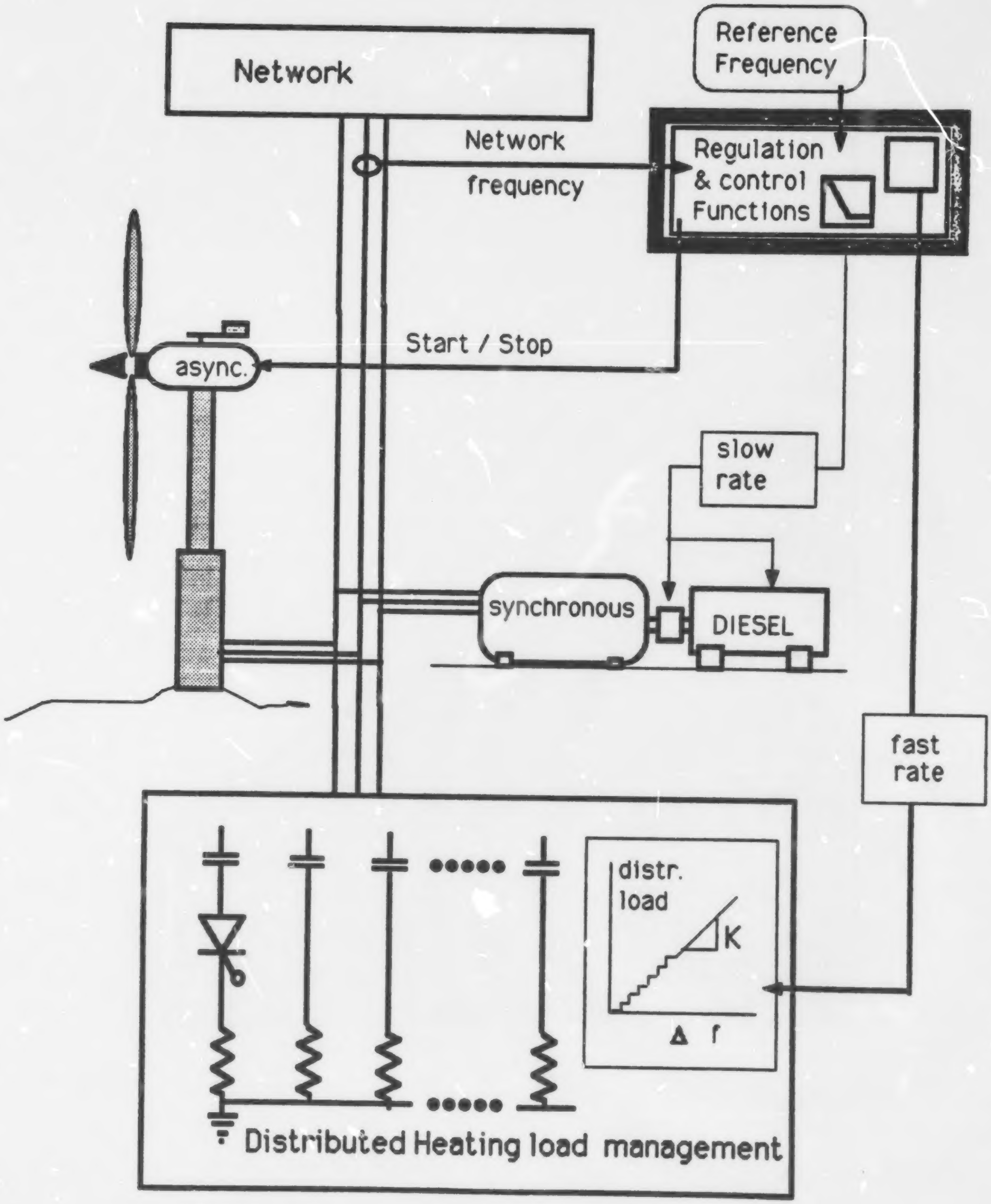
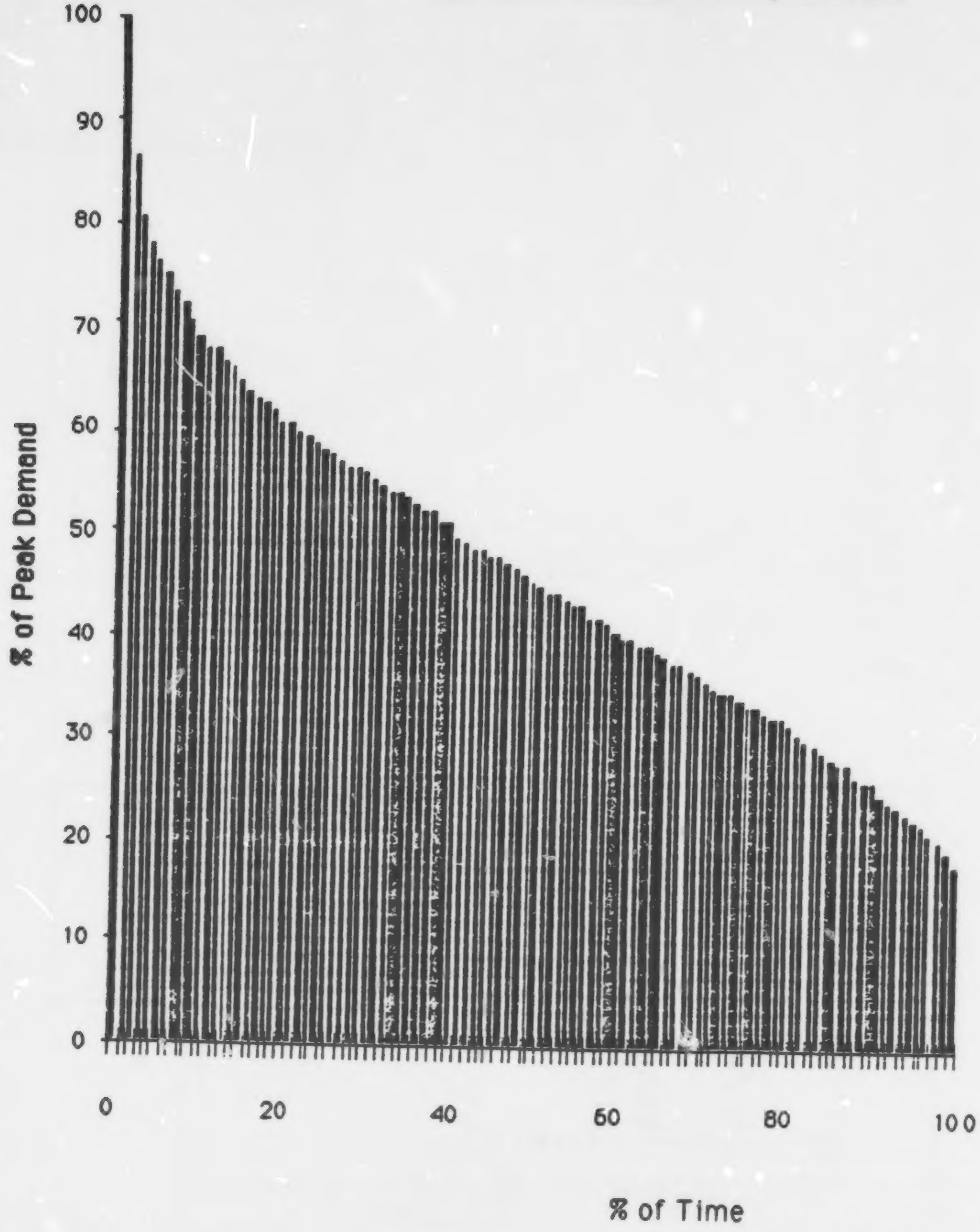

Network
Reference Frequency
Network frequency
Regulation & control Functions
Start / Stop
async.
slow rate
synchronous
DIESEL
fast rate
distr. load
K
Δ f
Distributed Heating load management

Figure 1 : Schematic of the no-storage high wind penetration W/D scenario

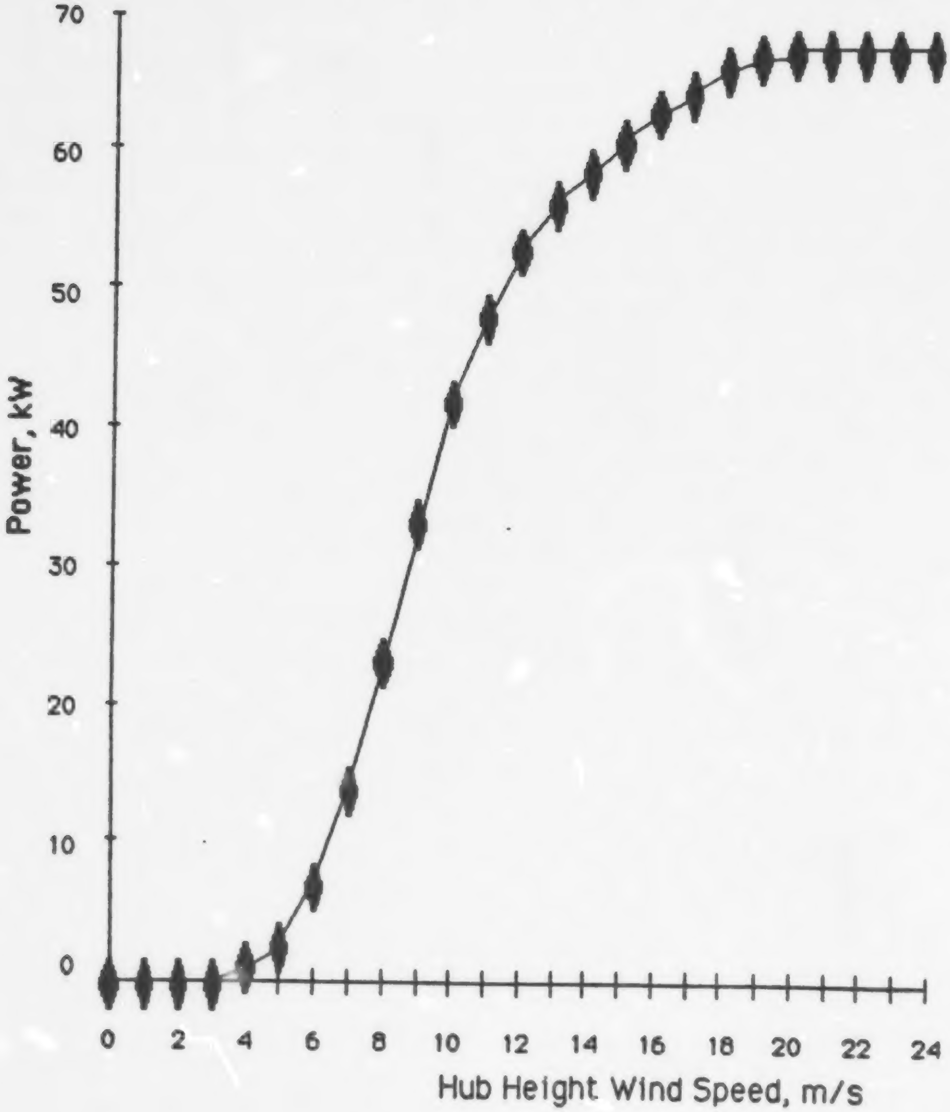
Figure 2 : Demand Probability Curve



Source: Vice-Présidence Planification Des Equipements, Hydro Québec.

Figure 3 **Typical Power Curve**

Danish 65 kW Wind Turbine



Source: Bonus Wind Turbine

Figure 4 **% Energy Rejected by the Network**

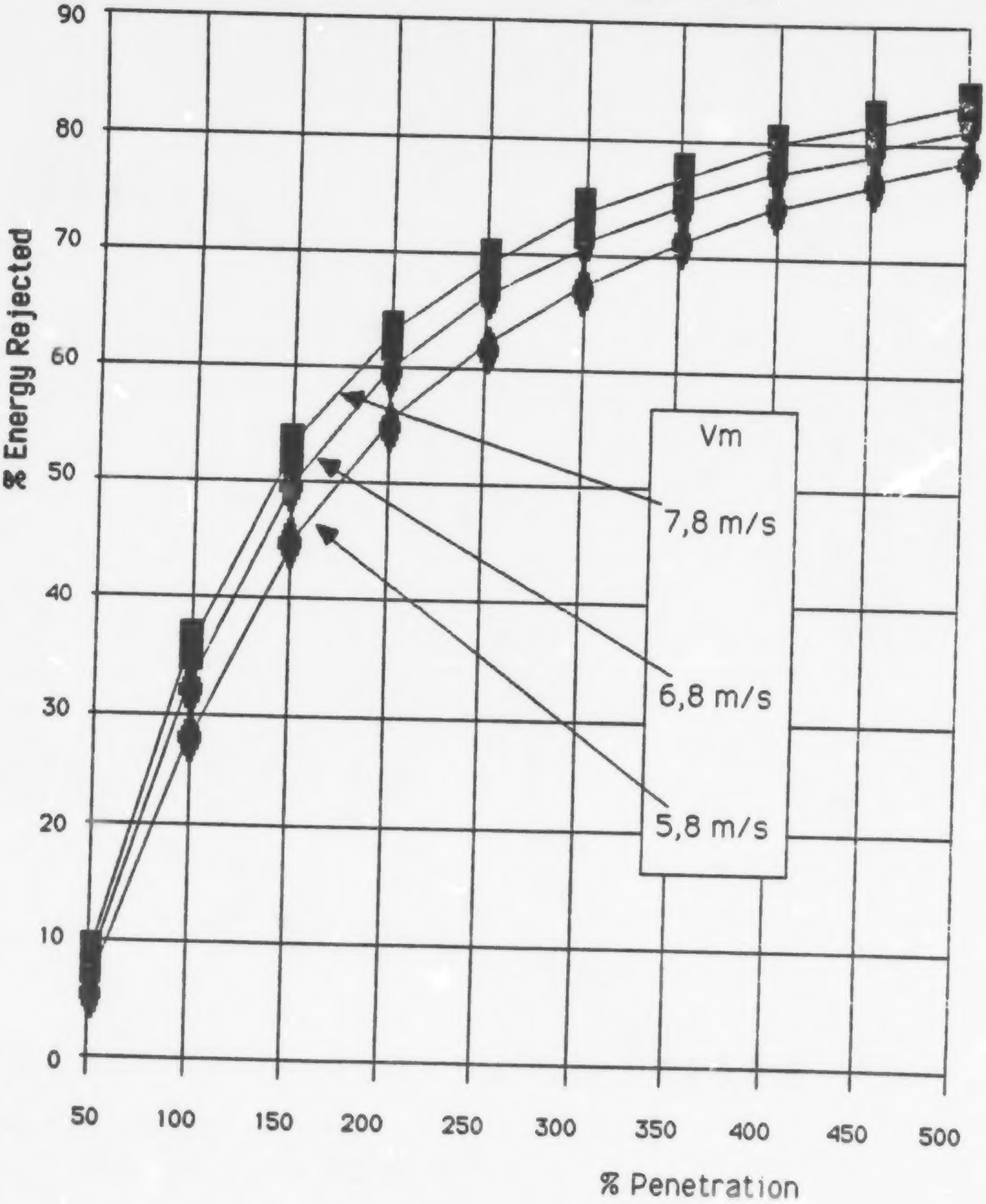


Figure 5 : **% Of Network Demand Supplied By Wind Energy**

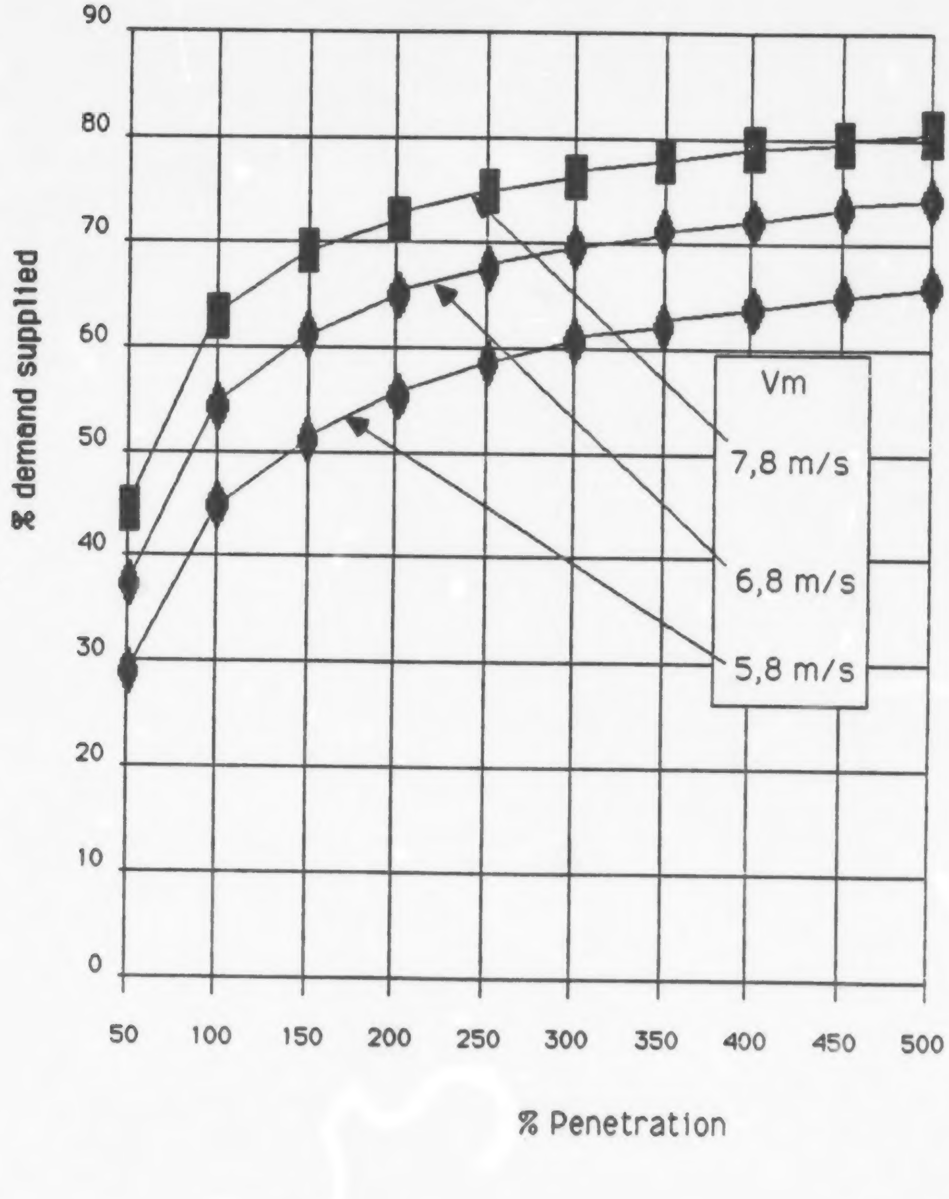


Figure 6 Total Net Present Value

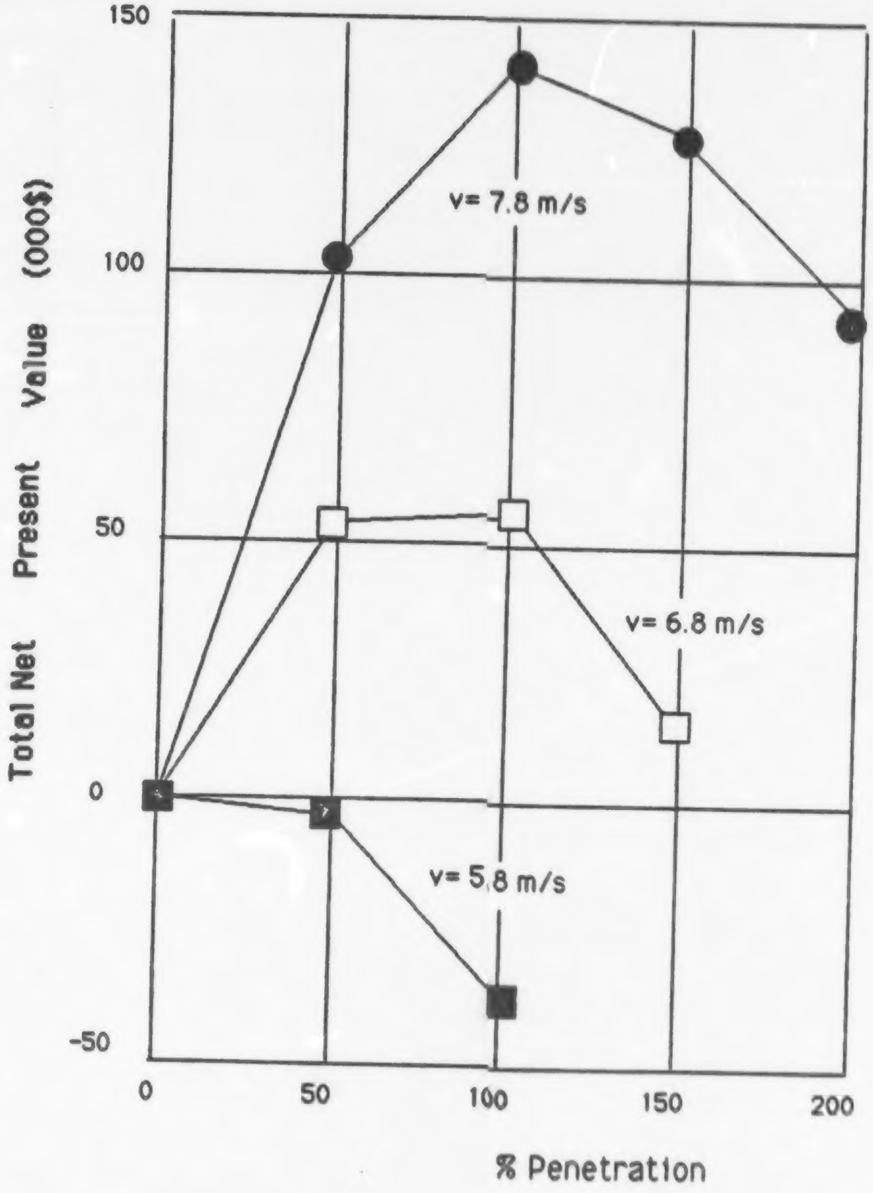


Figure 7 **Total Net Present Value, Sensitivity to Fuel Costs**

v= 5.8 m/s

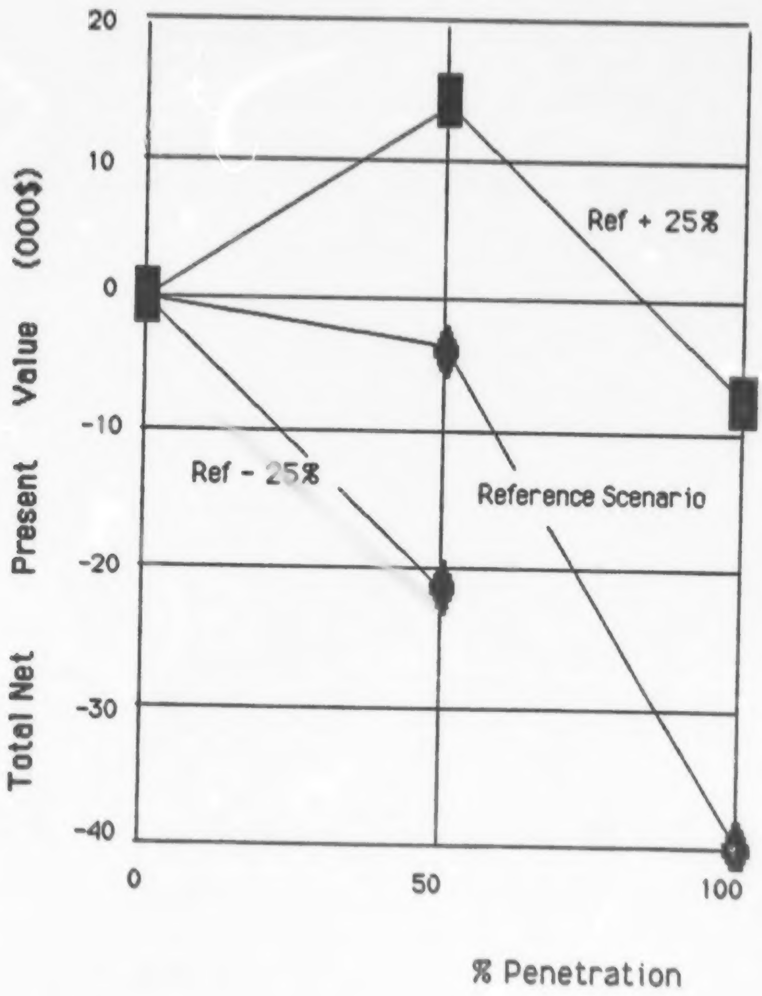


Figure 8 Total Net Present Value, Sensitivity to Fuel Costs

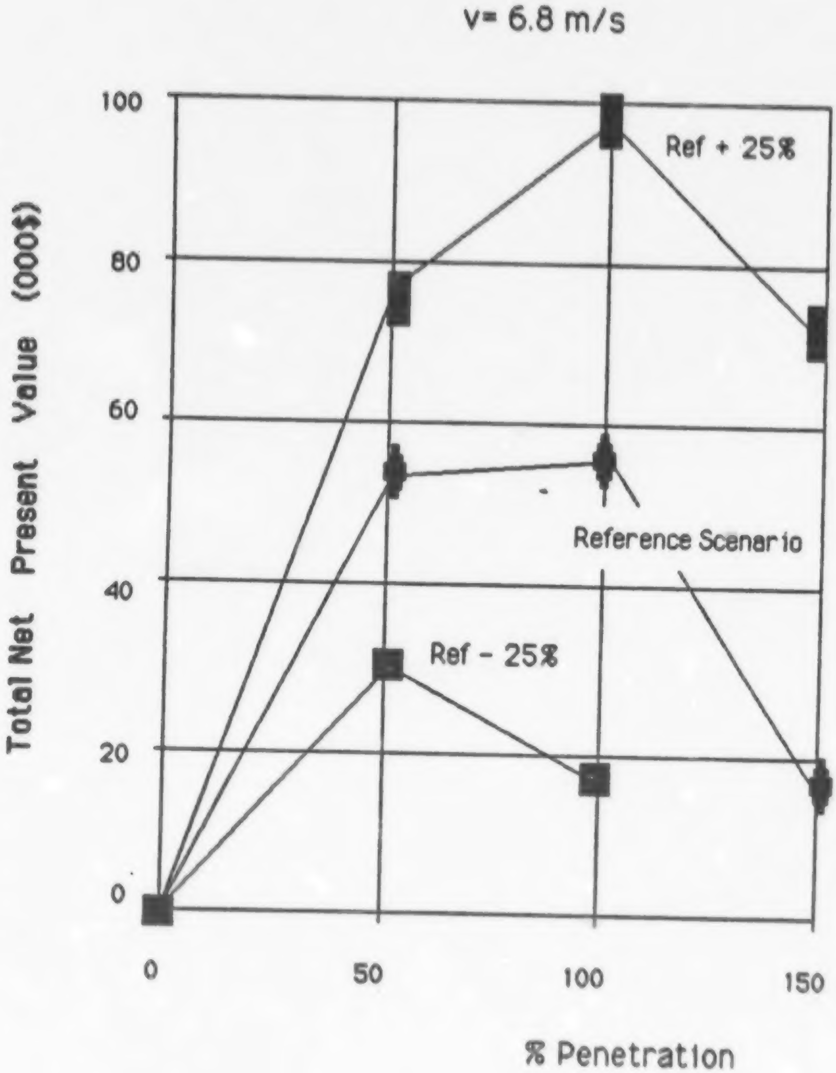


Figure 9 **Total Net Present Value, Sensitivity to Fuel Costs**

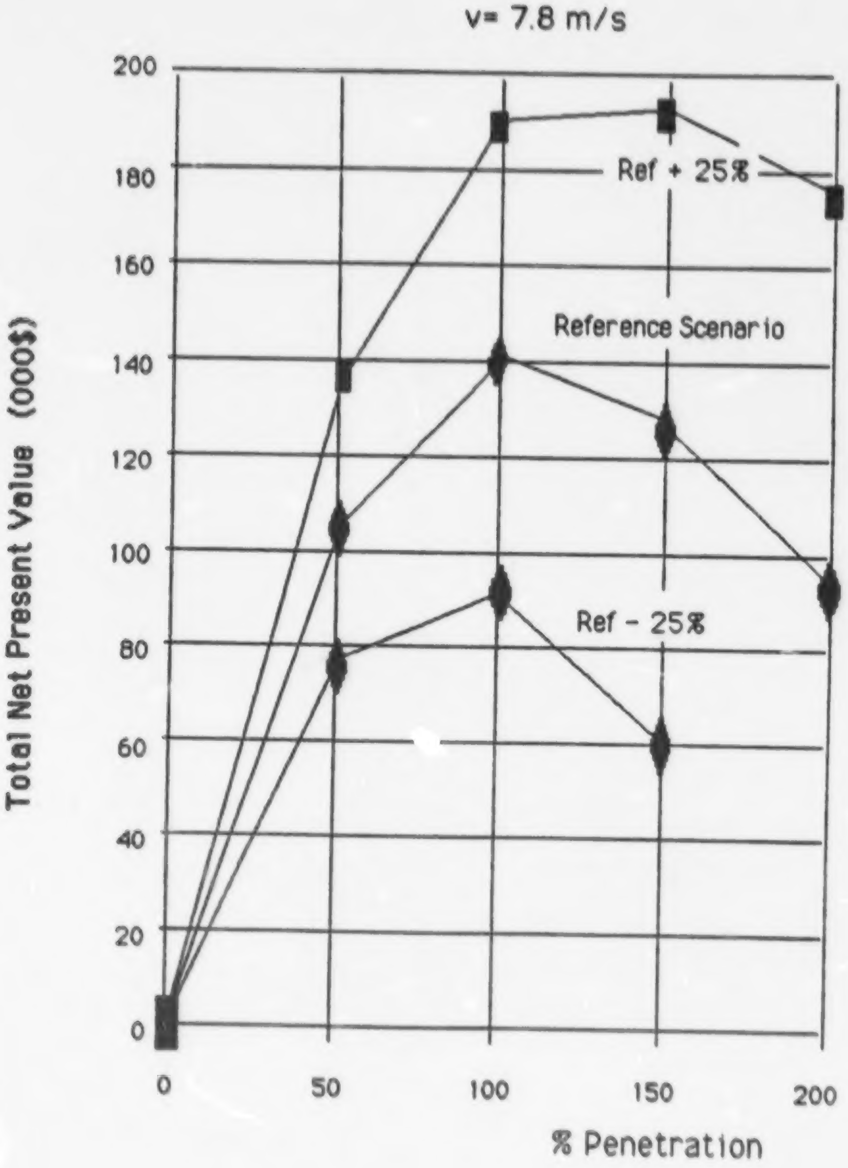


Figure 10 **Net Present Value/Turbine**

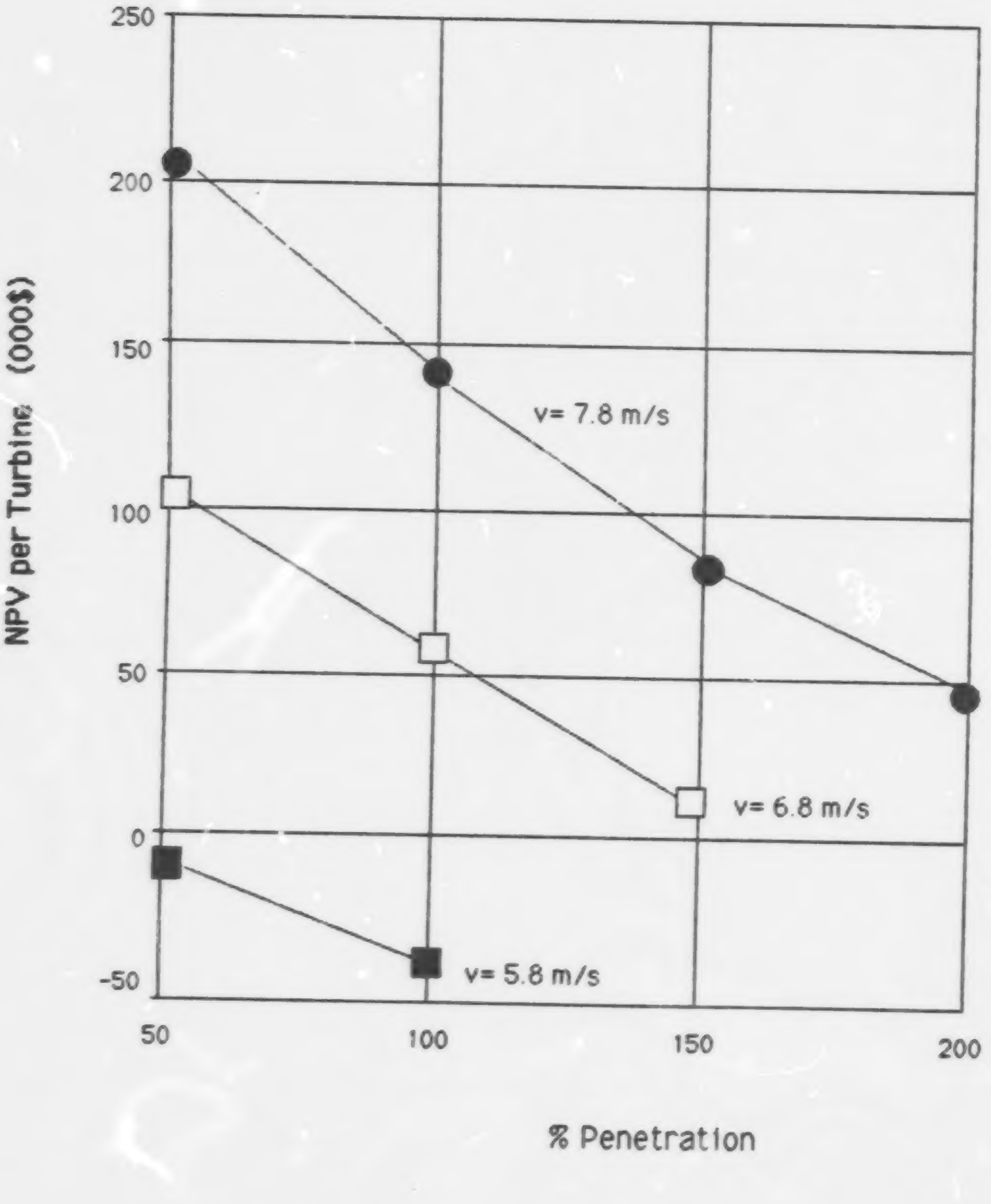


Figure 11 Internal Rate of Return

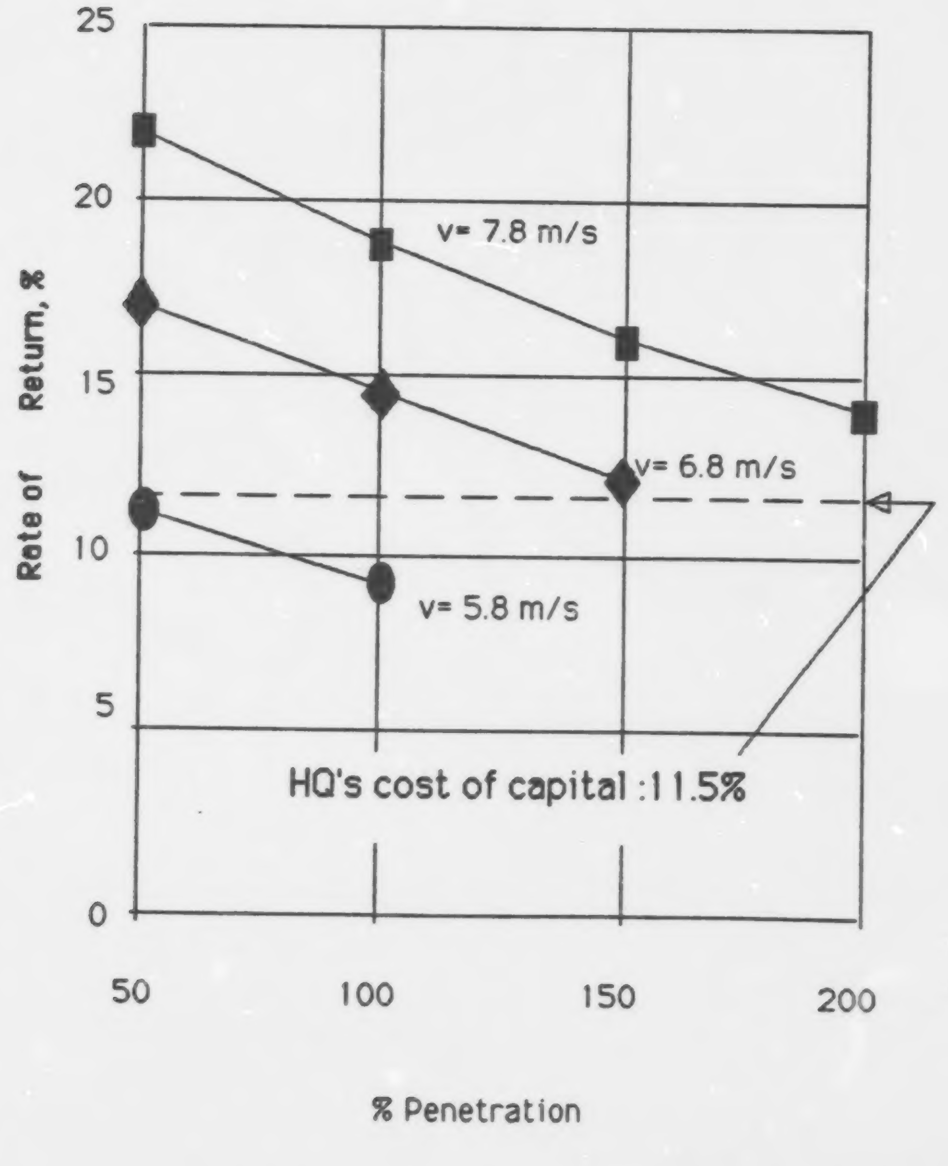


Figure 12 Pay Back Period

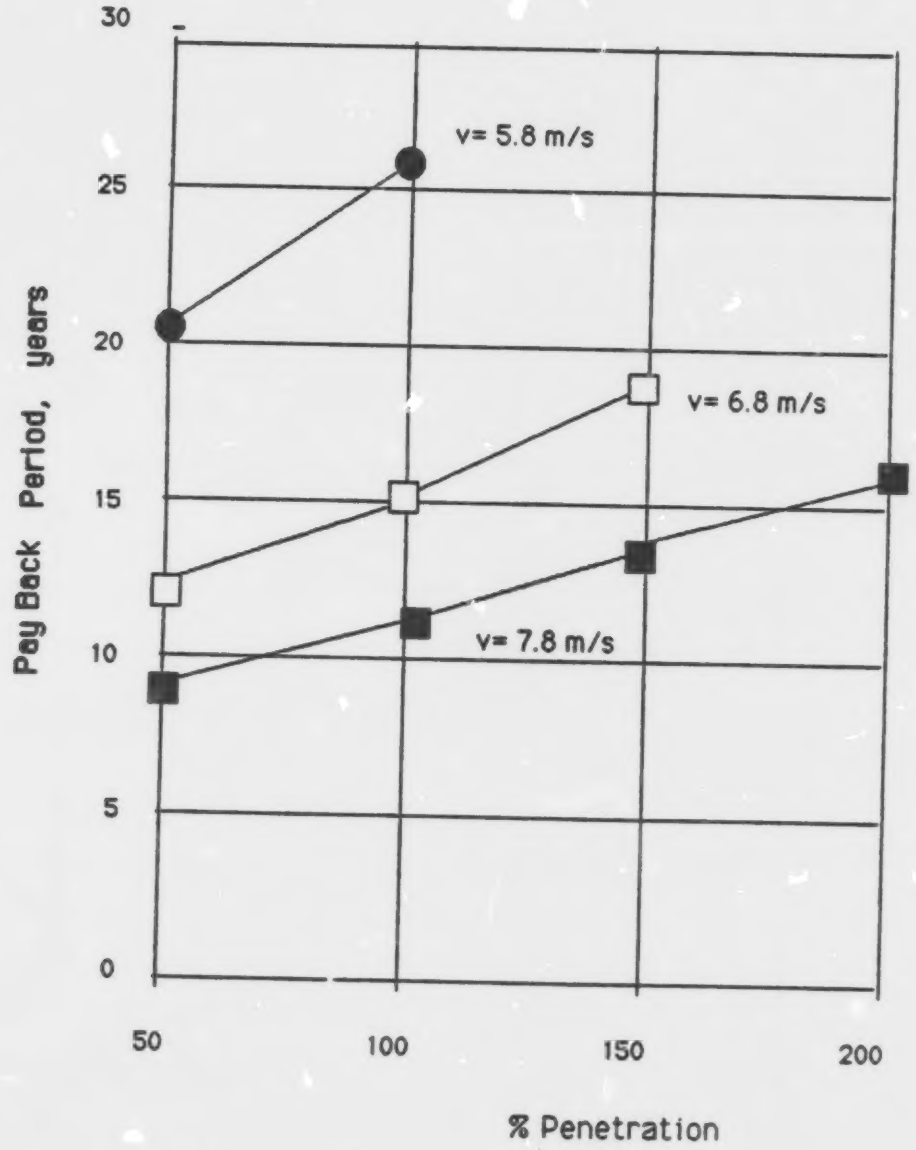


Figure 13

Pay Back Period, Sensitivity to Fuel Costs

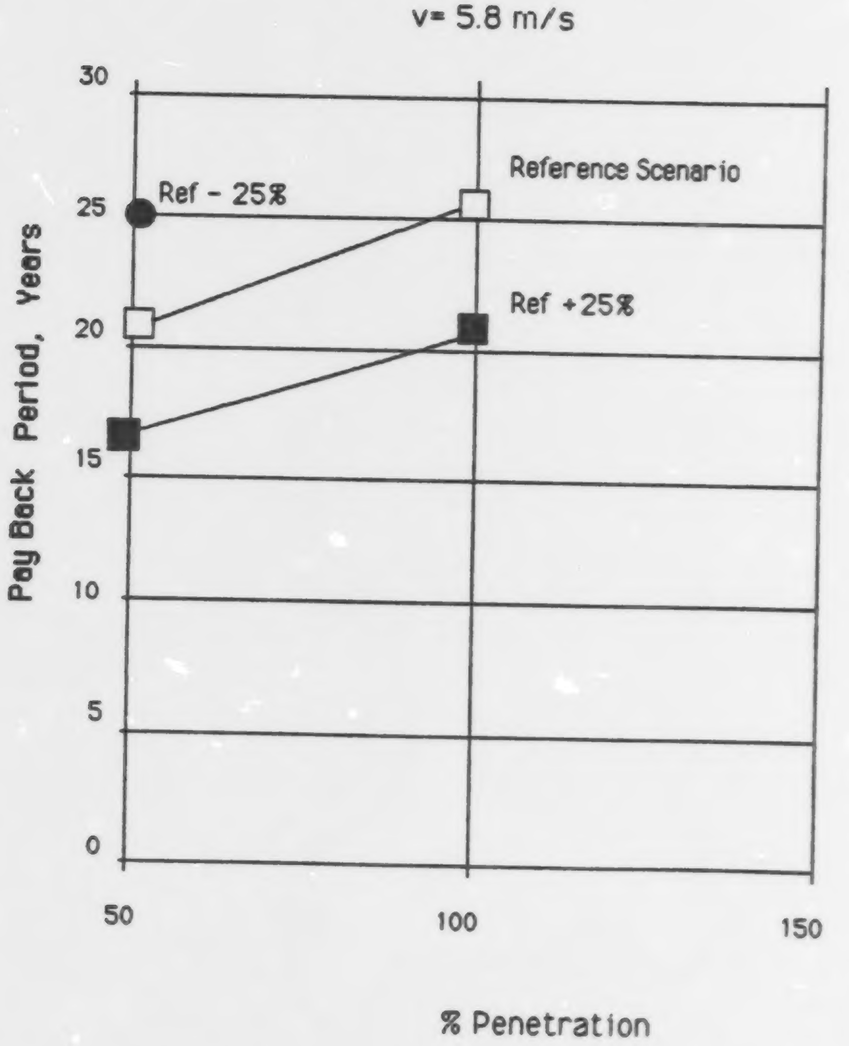


Figure 14

Pay Back Period

Sensitivity to Fuel Costs

v= 6.8 m/s

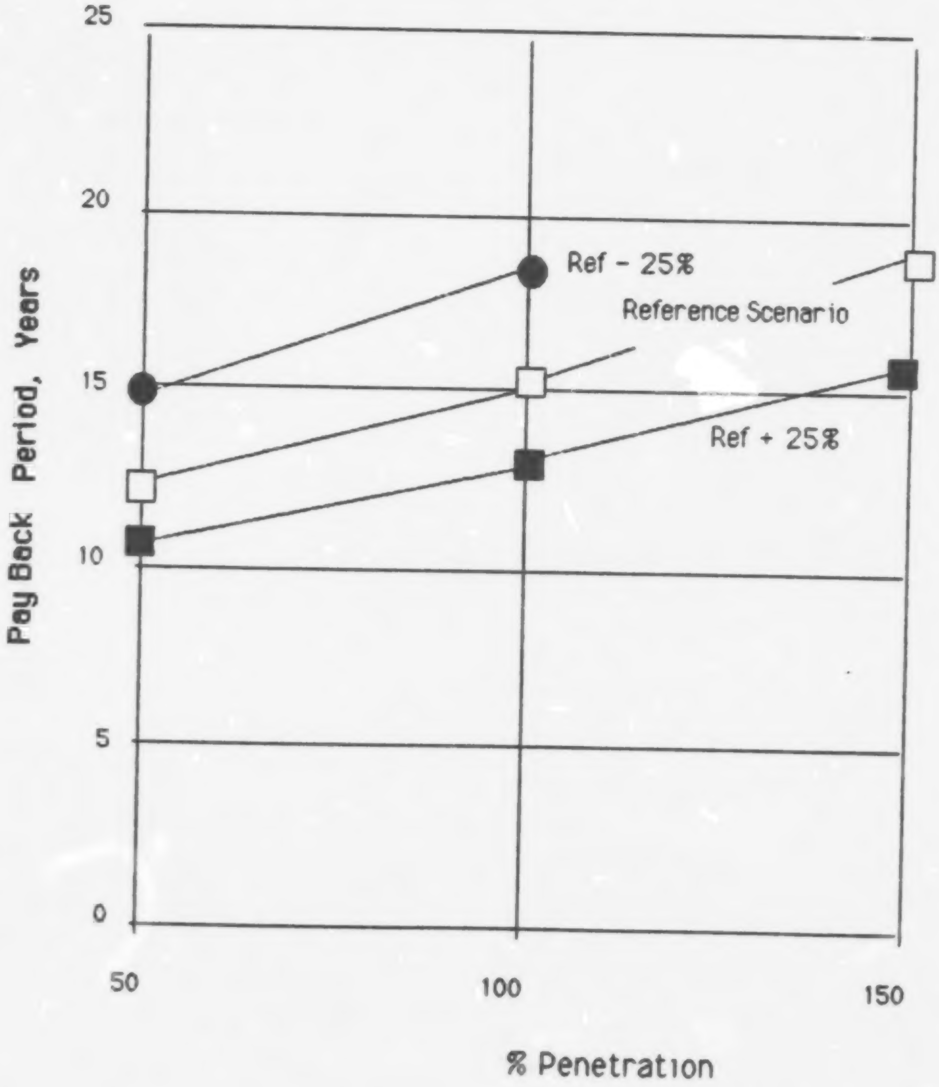


Figure 15

Pay Back Period, Sensitivity to Fuel Costs

v= 7.8 m/s

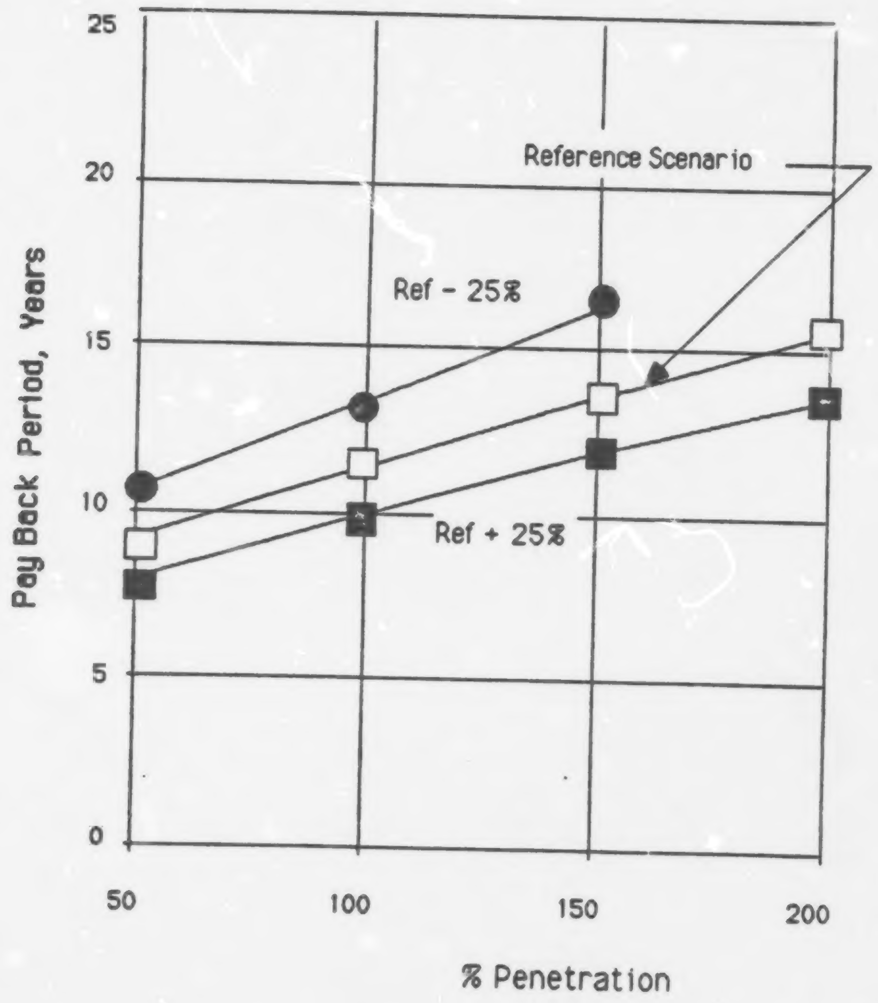
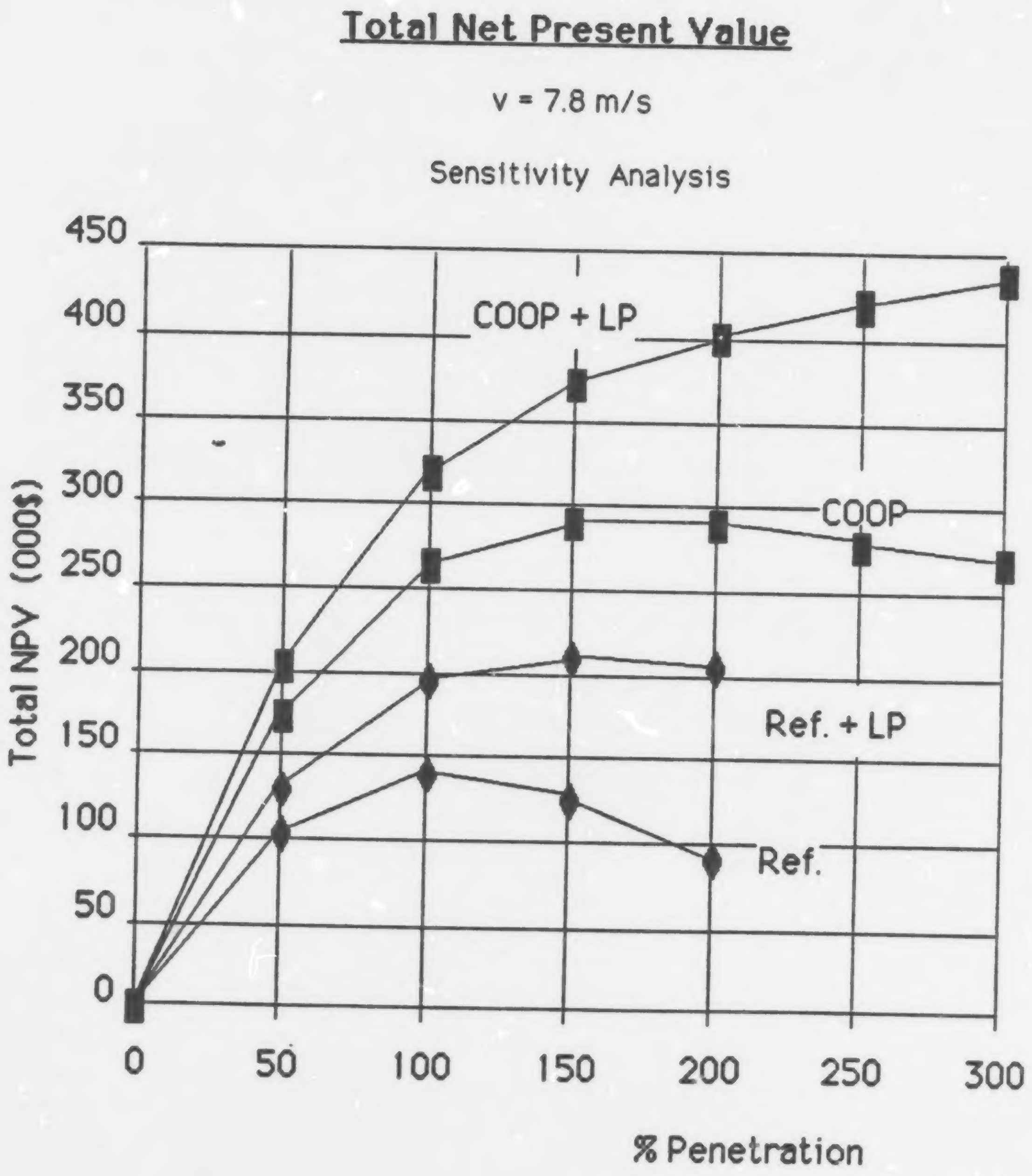


Figure 16


Total Net Present Value
v = 7.8 m/s
Sensitivity Analysis
Total NPV (000$)
450
400
350
300
250
200
150
100
50
0
0
50
100
150
200
250
300
% Penetration
COOP + LP
COOP
Ref. + LP
Ref.

TECHNOLOGY DEVELOPMENTS

INCREASED OUTPUT FROM DARRIEUS ROTORS

D.J. Malcolm

Indal Technologies Inc.
3570 Hawkestone Road
Mississauga, Ontario
L5C 2V8

Presented at the Canadian Wind Energy Conference,
Quebec City, 27 - 28 October, 1986

INCREASED OUTPUT FROM DARRIEUS ROTORS

D.J. MALCOLM

Indal Technologies Inc.

3570 Hawkestone Road, Mississauga, Ontario, Canada L5C 2V8

SUMMARY

The consequences of incorporating early-stall tailored airfoil blades on the Indal 6400 VAWT rotor are studied. The same (520 kW) power train is used while the energy capture is maximised for four different wind regimes. The results of a dynamic structural analysis of one of the rotors and the fatigue strength of typical connections suggest a limit to the size of rotor which uses a single-extrusion aluminum blade. The final decrease in cost of energy is conservatively estimated to range between 14% and 25%.

1. INTRODUCTION

The Darrieus rotor was first patented in 1931 but remained unexploited until its "rediscovery" at the National Research Council of Canada in 1969. Since that time considerable work has been carried out in Canada, both privately and publicly, to develop the technology required to use these machines successfully. The existence of several hundred Darrieus rotor wind turbines in California confirms that they can compete with horizontal axis wind turbines (HAWTs).

The fixed-pitch of the Darrieus rotor blades and the cyclic nature of the aerodynamic loads have resulted in peak coefficients of performance that are slightly lower than for HAWTs. However, the last few years have seen developments that may substantially improve the economic viability of Darrieus rotors especially in lower wind regimes.

The final cost of energy depends principally on three items (in addition to the wind regime): the initial capital cost (including installation), the cost of maintenance, and the total energy captured by the rotor. The energy capture is affected by solidity and rotor speed but once these have been optimized the only remaining method to increase output is by increasing the swept area. Unfortunately the power rating and the capital cost of many items are also usually closely related to the swept area so that the final cost of energy is not necessarily reduced.

The need to increase energy capture without increasing the rated power has led Sandia National Laboratories, New Mexico, to develop a family of "tailored airfoils". These airfoils are designed to stall at an earlier angle of attack than the NACA00 series that have been used until now. Considerable wind tunnel testing on both static and oscillating airfoils have been carried out and experimental results are now available from the 17-m test machine which was fitted with tailored airfoils (1,2).

The philosophy of tailoring the type and size of airfoil to its location on the blade is being applied by Sandia Laboratories to their large test bed which is at present under construction (3). The majority of the useful power is generated by the central one-half of the blade where the tailored airfoil is therefore installed in order to control the maximum output. The remaining blade sees lower tip speed ratios than the central half and is therefore of most use at lower wind speeds. For this reason and for structural reasons these lengths of blade are of greater chord and of NACA00 section.

By maintaining the rated power constant, the cost of the transmission and the electrical equipment will be affected only slightly. The only major cost increase is expected to be material cost in the rotor but this, it is hoped, will be greatly outweighed by the greater energy output.

2. OBJECTIVES AND PROCEDURE

This paper presents some results of a study which was funded in part by Indal Technologies and also by the Department of Energy, Mines and Resources, Ottawa. The purpose of the study was to obtain preliminary estimates on the decrease in cost of energy when the principles of tailored airfoils were applied to the Indal 6400 VAWT (520 kW); this phase precedes detailed engineering and market evaluation. The assumptions made and procedures followed are summarized below.

(1) The maximum electrical power was limited to 520 kW. This corresponds to the present Indal 6400.

(2) The formula for total drive train power loss was 20 kW plus 10% of the aerodynamic power generated.

(3) Airfoil lift and drag coefficients as supplied by Sandia National Laboratories and the National Research Council of Canada were used.

(4) Four wind regimes were examined: two mean windspeeds (at 10 m height) of 6.2 m/s (14 mph) and 8.0 m/s (18 mph) and two distribution types, having Weibull shape factors K=2 (a Rayleigh distribution) and K=3. The combination of a 6.2 m/s mean and K=3 corresponds to many trade wind sites.

(5) Two new rotor configurations were considered: one used a blade with a constant 0.762 m (30 in.) chord; this is considered to be the maximum size obtainable as a single aluminum extrusion. The second configuration used a blade having a step-tapered chord of up to 1.32 m (52 in.) implying a multiple extrusion or other fabricating technique.

(6) The rotors were assumed not to be supported on towers (only on the required power modules) and a wind shear exponent of 0.16 was used.

(7) 100% availability was assumed.

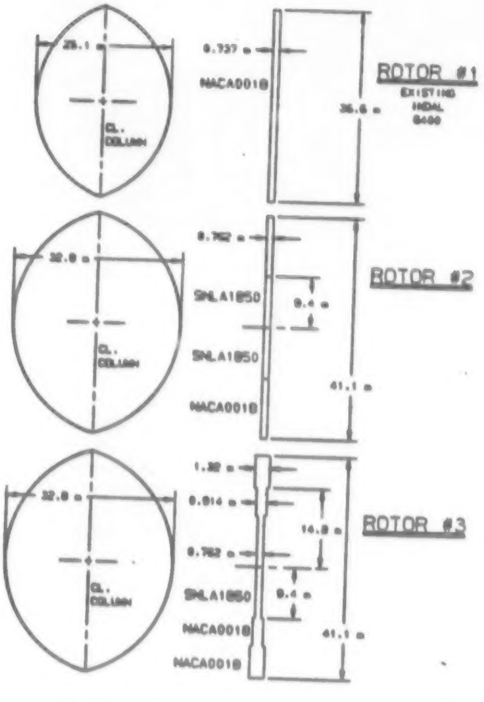
3. ENERGY OUTPUT

3.1 Calculation of Power Output

The performance of the rotors was calculated using a computer program that utilized the double multiple stream tube model. The program incorporated a dynamic stall routine based on the Gormont model having the Masse-Templin modifications. The performance curves obtained in this way at the specified rotor speeds were integrated with the wind speed distribution to produce the annual energy output estimates.

3.2 Selected Rotors

The three rotors examined, the existing Indal 6400 and the two modified rotors, are shown in Figure 1.



28.1 m
0.737 m
NACA0018
36.6 m
ROTOR #1
EXISTING INDAL 6400
CL. COLUMN
32.0 m
0.762 m
SNLA1850
9.4 m
SNLA1850
NACA0018
41.1 m
ROTOR #2
CL. COLUMN
32.0 m
1.32 m
0.914 m
14.0 m
0.762 m
SNLA1850
9.4 m
NACA0018
NACA0018
41.1 m
ROTOR #3
CL. COLUMN

Fig. 1. Details of three rotor configurations

3.3 Comparison of Results

The rated power and the annual energy output in the four wind regimes at several rotor speeds was calculated and the results are shown in Fig. 2. The output of each configuration when the rated power is limited to 520 kW is summarized in Table 1. The corresponding performance curves are shown in Fig. 3.

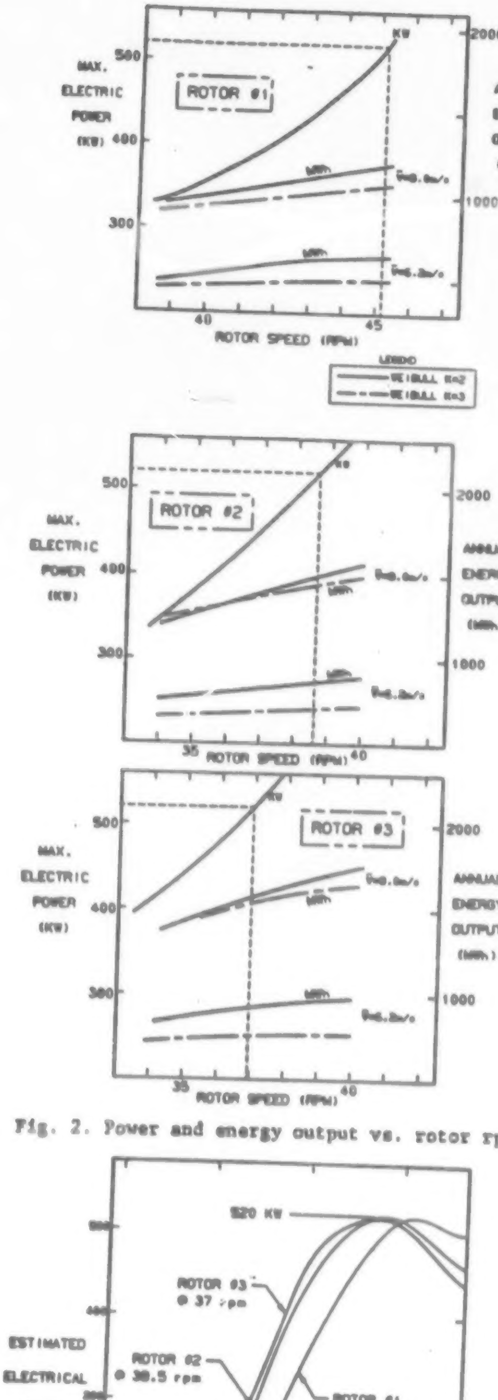


Fig. 2. Power and energy output vs. rotor rpm

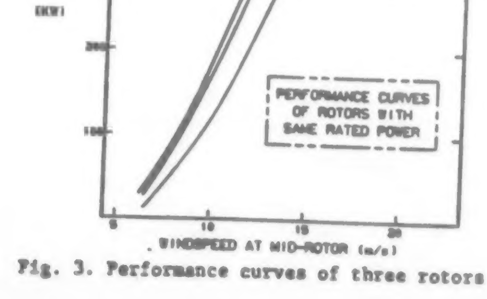


Fig. 3. Performance curves of three rotors

Table 1. Summary of energy output of each rotor

	Rotor #1	Rotor #2	Rotor #3
height, m	36.6	41.1	41.1
diameter, m	25.1	32.8	32.8
height, diameter	1.45	1.25	1.25
swept area, m^2	6.02	891	906
rotor speed, rpm	45.0	38.5	37.0
max. electrical output, kW	520	520	520
$\overline{V}$ = 8.0 m/s, K = 2	1178	1500	1573
annual output, MWh	(+0%)	(+27%)	(+33%)
energy capture, MWh/m^2	1.96	1.68	1.74
$\overline{V}$ = 6.2 m/s, K = 3	500	720	768
annual output, MWh	(+0%)	(+44%)	(+54%)
energy capture, MWh/m^2			

The following comments can be made on these results.

(1) The greater energy capture by rotors #2 and 3 is most apparent in the lower wind regime, when the energy capture per unit area may also increase.

(2) The maximum power of all rotors increases rapidly with rotor speed whereas the energy output at $\overline{V}$ = 6.2 m/s, K = 3, is relatively insensitive to rotor speed. This implies that a lower speed rotor may be the economic optimum for such wind regimes.

(3) In the higher wind regime (8.0 m/s mean) rotors #2 and 3 will capture almost as much energy whether the Weibull K = 2 or K = 3. They are less sensitive to the exact wind speed distribution.

4. STRUCTURAL ANALYSIS AND DESIGN

Preliminary design and structural analysis of rotor #2 was carried out in order to determine whether the configuration was technically feasible. Based upon these results, conclusions were drawn on the feasibility of rotor #3.

4.1 Procedure

The analysis procedures used were essentially those established earlier at Sandia National Laboratories with a number of simplifications. For a Darrieus rotor it is necessary to include the differential stiffening effects from centrifugal forces as well as the softening and Coriolis effects due to rotation. The general purpose program NASTRAN allows these effects to be incorporated. More details of this procedure have been published elsewhere (4).

4.2 Design for Fatigue

Experience has confirmed that high cycle fatigue loading is a critical design condition for both horizontal and vertical axis machines. To design for this condition it is necessary to know both the expected stresses and the "S-N" curve for the particular detail. The blade root and splice connection used on the Indal 6400 has undergone laboratory fatigue tests resulting in the S-N curve shown in Figure 4. The fatigue limit apparent from these tests was in close agreement with other information for bolted aluminum connections.

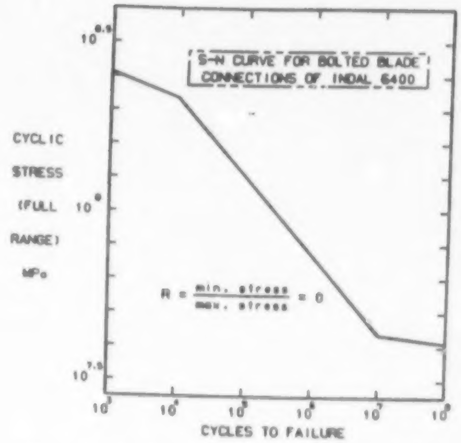


Fig. 4. Fatigue strength of bolted blade connections

In order to determine the life expectancy of any connection the method outlined in reference (5) was used. Some results from the application of this method to the S-N curve of Figure 4 are summarized in Figure 5. That Figure confirms that longer lives may be expected under lower wind regimes but implies that an rms value of 14 MPa (2000 psi) at V = 20 m/s (45 mph) should be an upper limit. Environmental conditions such as marine corrosion can lead to a lower limit.

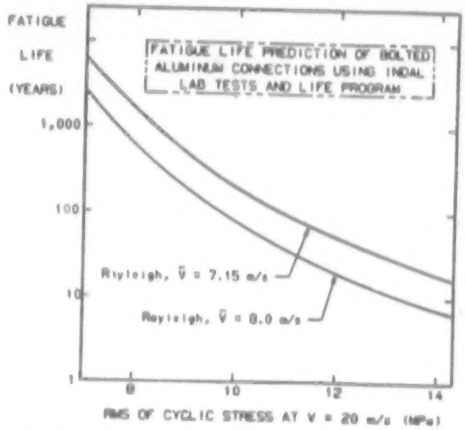


Fig. 5. Fatigue life predictions vs. rms stress

4.3 Analysis Results

The key to any successful wind turbine design is to avoid any resonant conditions. For a Darrieus rotor this may be accomplished by adjustment of guys, the central column, the blade chord and the location and stiffness of the horizontal struts. The results that are presented in Table 2 for rotor #2 in a 20 m/s windspeed are, therefore, preliminary; they can be improved by further tuning of the structure.

Table 2 shows that at the lower root the rms of the cyclic stresses exceeds the limit of 14 MPa established above. This stress could be lessened by stiffening the struts and possibly by moving them further from the roots.

Table 2. Blade stresses in rotor #2, windspeed = 20 m/s

Location		Mean	1P	2P	3P	Standard Deviation
lower root	LE	3.4	12.8	4.5	12.7	10.6
	TE	35.6	15.3	5.7	16.1	16.3
at lower strut	LE	3.2	9.8	2.6	7.6	9.1
	TE	29.1	11.6	3.3	9.8	11.1
	IF	33.2	0.6	4.0	8.2	6.5
at upper strut	LE	7.9	11.7	2.8	7.1	9.9
	TE	29.0	12.9	2.9	7.2	10.7
	OF	33.9	4.5	6.4	8.9	8.5
upper root	LE	5.9	14.3	3.5	7.3	11.7
	TE	34.3	16.1	3.9	7.0	12.8

*All stresses are in MPa
*1P, 2P and 3P are ± values at multiples of the rotorspeed.
*LE = leading edge
TE = trailing edge
IF = inner face
OF = outer face

5. COST ESTIMATES

The cost of supplying each of the three rotors was estimated based on the following assumptions.

- The installation is a 30 machine windfarm.
- Taxes, duty, overheads and profit are included.
- Transportation and installation are not included.
- Costs of connection to an electrical grid are not included.
- The costs of the blades and central column are directly proportional to their weights.
- The costs are 1985 Canadian dollars; however this is not important in the present study.

These costs are summarized in Table 3.

Table 3. Cost estimates and cost effectiveness

Item	Rotor #1	Rotor #2	Rotor #3
rotor assembly	$172,000	$221,500	$245,500
rotor support	61,400	62,800	62,800
drive train	203,600	203,600	203,600
electrical	65,000	65,000	65,000
total	$502,000	$552,900	$576,900
	(+0%)	(+10%)	(+14%)
$/MWh (V=8.0 m/s K=2)	426	368	366
	(-0%)	(-14%)	(-15%)
$/MWh (V=6.2 m/s K=3)	1004	768	751
	(-0%)	(-23%)	(-25%)

There are many methods of calculating the cost of power generated by a wind turbine; indeed each installation and financial arrangement will be unique. In this paper it is sufficient to use the ratio of annual energy to capital cost as a measure of cost effectiveness. These ratios are included in Table 3 for two of the wind regimes.

Table 3 shows that there should be a considerable decrease in the cost of energy between rotors #1 and 2 or 3, especially in the lower wind regime. These estimates are conservative because they do not include the costs of transportation and installation; these may typically amount to 50% of the wind turbine cost.

6. CONCLUSIONS

This study has demonstrated the considerable cost effectiveness of including Sandia National Laboratories tailored airfoils into the profile of a Darrieus rotor. The study has focused on the rotors that have the same rated power as the existing Indal 6400; this was done because a proven power train was available and the intent was to maximize the energy output. However, similar studies might wish to maintain a constant low speed torque as a base line.

The structural analysis of rotor #2 shows that these dimensions probably stretch to the limit the capabilities of a single aluminum extrusion blade; from this it may be concluded that it would be wise to consider rotor #3 or to reduce the scale of rotor #2 so that fatigue stresses at connections are less critical.

Rotor #3 with a tapered chord is slightly more cost effective than rotor #2, so long as the greater cost of fabricating the blades does not escalate. This extra cost has been assumed to be proportional to the additional mass associated with the design; this may be conservative. The value of the tapered chord may be affected by the size of the rotor since all large rotors will be forced to adapt airfoil chords greater than those obtainable from a single aluminum extrusion; for smaller rotors the tapered chord or multiple extrusion blade is not essential. Progress in the technology of blade manufacturing will greatly affect the configuration selected.

Examination of how the energy output changes with rotor speed confirms that rotors and rotor speeds should, ideally, be adapted for the intended wind regime. The relative insensitivity of energy output to rotor speed in trade wind sites suggests that a lower speed rotor might be considered.

7. REFERENCES

(1) Klimas, P.C., "Tailored Airfoils for Vertical Axis Wind Turbines", SAND84-1062, Sandia National Laboratories, Albuquerque, N.M., November 1984.

(2) Klimas, P.C. and Worstell, W.H., "Performance Testing of the Sandia National Laboratories 17-m Diameter Research Turbine with Natural Laminar Flow Blade Elements", Fifth ASME Wind Energy Symposium, New Orleans, February 1986, Ed. A. Swift.

(3) Berg, D.E. and Ashwill, T.D., "An Update on the Structural Design of the Sandia 34-m Vertical Axis Wind Turbine", Fifth ASME Wind Energy Symposium, New Orleans, February 1986, Ed. A. Swift.

(4) Lobitz, D.W., "Forced Vibration Analysis of Rotating Structures with Application to Vertical Axis Wind Turbines", Proceedings 5th Biennial Wind Energy Conference and Workshop, Washington, D.C., Oct. 5-7, 1981, SERI/CP-635-1340.

(5) Veers, P.S., "Blade Fatigue Life Assessment with Application to VAWTs", J. of Solar Energy Engineering, Vol. 104, May 1982, pp. 106-111.

OPTIMIZATION IN WIND TURBINES

John Ereaux - ADECON Energy Systems Inc.

The wind energy effort — the modern history of which began with renewed vengeance in the last decade — is now moving beyond the research labs of inquisitive scientists and the artificial environments of tax credit financing to a more mature, viable option for energy production. In doing so, we should remember that wind energy is in direct competition with other well-established sources of electrial energy production and as a result rigid constraints are placed on the development process. To be successful, wind energy must always match or better the cost of energy over those existing alternative sources. To reduce the cost of energy, or in different terms, to optimize the aerogenerator for its specified purpose, it is necessary to analyse the system in a logical manner.

It is possible to show that the optimization of a wind turbine is simply the process of maximising the benefit to cost ratio. The primary benefit produced by the wind turbine is the energy production and if we ignore the effect the quality of the power has on the value, we can assume that the benefit of the turbine is proportioned to the energy production. Thus, the optimization process becomes one of maximising the energy production to cost ratio.

Ideally, the benefit-to-cost analysis would include environmental and social consequences of energy production both as benefits and costs, but in the sphere of presentday economic and legislative thinking this is not a consideration. What is considered are the capital and life cycle costs of operation of the aerogenerator and the total energy production delivered with some weighted factor included for the ability to deliver that energy on demand. If aerogeneration can be optimized even within this narrow definition of cost of energy, we have the opportunity to compete with, and perhaps displace, the less desirable of existing sources of energy.

If the costs and benefits of the aerogenerator are functions of some number (say n) independent variables, then the generalized mathematical expression of optimization can be expressed by

$$\frac{\partial B}{\partial x_i} \bigg/ \frac{\partial C}{\partial x_i} = \dots = \partial B/\partial x_n \big/ \partial C/\partial x_n = \frac{B}{C}$$

at the optimum

where B is the benefit

and C is the cost.

In practice, we do not know the value of any of the derivatives over an extended range so an exact solution is not possible. However, it is possible to calculate the derivatives about some particular point and to determine the types of changes that are required to bring the overall configuration closer to the optimum.

The change in energy production caused by an incremental change in any of the independent variables can be calculated, and if this change of energy is compared with the cost of making the incremental change the direction of the optimum can be established. In practice, it is very difficult to accurately estimate the true cost of making a change in a variable since changes in one variable can force changes in [illegible] others. A change in solidity, for instance, can force changes in installed power, rotor RPM, shaft torque, aerodynamic loads, etc. and the impacts of all these factors must be considered.

An alternative approach is to fix the energy production of the wind turbine. The optimization problem then becomes one of comparing the costs of the offsetting changes that must be made in the other variables to compensate for the changes in the primary variable. If the sum of the changes causes a decrease in the cost of the system, then the changes are bringing the system closer to the optimum.

In some cases the wind turbine configuration will have some limitations. It may be required to have some particular overall dimension or to produce some particular annual amount of energy. These requirements may force a configuration that is not a true optimum. However, it is still possible to use optimization techniques to get the best configuration for a particular job.

Also important in the optimization process is the need to optimize the

engineering efforts dedicated to the task, and as such it is necessary to develop a logical agenda for the cost-to-benefit analysis.
The priority of each variable or component in the optimization agenda will vary between different aerogenerators reflecting the importance with which that component has in a particular design. One might conclude that the potential for benefit-to-cost improvements might be related to the raw cost and in a simplistic way this is true; however, the impact on the present value of the life cycle costs can be quite different rendering inexpensive components extremely important in the optimization process.

*

To illustrate, let us consider the optimization techniques employed during the development of the ADECON 19 METER. In the case of this aerogenerator nothing was taken as sacred. The only requirement was for a cost-effective wind machine. The starting point of this design was based upon two technically arbitrary decisions: approximate installed power and a particular transmission size. These decisions were the recommendations of a thorough market analysis of aerogenerator sales and transmission availability and cost.

Initially key parameters such as rotor solidity, height to diameter ratio, turbine speed, swept area, installed power and maximum shaft torque were worked and reworked through the various performance codes available for vertical axis wind turbines to develop a thorough understanding how these parameters interrelated in terms of performance. This process is in itself vast and is the subject of another paper by my colleague Peter South. Some choices, such as one versus two versus three blades, were made based on experience and analyses of structural dynamics. Recognizing that the transmission represented the most costly item, is offered with limited selection and is sized not so much on maximum power but on maximum shaft torque, various configurations were tried each in the interest of optimizing the energy capture. Eventually a configuration was developed which favourably compromised the requirement for conversion efficiency and low component cost utilizing commercially available subsystems whenever possible.

The transmission itself offered little hope for cost improvements due to the already highly competitive nature of the market. What was possible was to select a configuration which maximised the energy output for a given gearbox size. This can be increased by modifying the load history by reducing the cyclic components of torque, peak start-stop loads and by limiting maximum power. Hence the selection of a low solidity, lightly loaded rotor and the development of lead-lag blade root hinges for torque ripple attenuation. Of course all the components of the chosen configuration carry with them some burden in terms of direct costs and an impact on energy production be it positive or negative. Hence each component needs to be considered and optimized separately.

In addition to the rotor geometry-transmission combination, the other main design variable offering a great degree of flexibility is the rotor support system. In the case of the ADECON 19 METER, optimization techniques were applied to optimize the structural elements for the lowest cost of energy. During this study it was seen that appreciable savings could be made in turbine costs if the weight of the rotor could be decreased and the guy tension loads eliminated so that the rotor could be carried directly on the thrust bearing of the transmission. This led to two innovations: the rigid external frame and the lightweight blade section.

The rigid frame is the product of a study which examined the life cycle costs of the entire rotor support system and its impact on energy production. One of the features of the external frame is structural capacity, which permits the raising of the turbine centre height to benefit from the higher winds found with increased height. This offers a classic example of optimization techniques, for each added foot in centre height carries with it a net increase in energy production and a corresponding incremental cost of structure. In this case it is fairly easy to construct a benefit-to-cost relationship. The process will be optimized when a height has been reached where the benefit-to-cost ratio is a maximum.

The lightweight blade section evolved after a study revealed that the rotor weight was limited on the low end by the conventional manufacturing process of the blades. A redesign of the blade structure permitted the use of multi-element open section extrusions, cutting rotor weight and costs by half. In this case a new manufacturing technique offered reduced cost, no net increase in energy production but in the long run a reduction in cost of energy.

Apart from the primary design variables just described, many of the smaller subsystems and components also offer potential for cost of energy reductions. One such component is the generator. Following recent generator technology, a premium efficiency generator was compared with a standard efficiency unit. The premium efficiency generator costs were about $1000 more than the standard efficiency but increased the energy output by about 10,000 kWh/year. With moderate interest rates and reasonable energy buy-back rates (often non-existent in the country) the premium efficiency is far more valuable than the standard efficiency. Hence, in this particular case, an increase in component cost actually lowered the cost of energy.

In another costing study, the raw costs of the struts were calculated at approximately $500.00 or less than 1% of the total turbine cost. Struts can have a significant impact on the energy production, however. On the ADECON 19 METER 150 kW machine, they can easily lose 10,000 kWh/year if not carefully designed hence careful design is far more important than raw cost.

Many other examples could be cited here and only the imagination can limit them. Perhaps one point to recall is that optimization is not simply cost reduction. It is cost of energy reduction. The design of a low cost aerogenerator or a highly efficient energy conversion system are important accomplishments and have a direct link in the path of achieving low energy costs, but if isolated from each other the optimization process is ignored.

*

A WIND TUNNEL INVESTIGATION OF AEROBRAKES FOR VERTICAL AXIS WIND TURBINES

P.J. Penna

National Research Council Canada
Low Speed Aerodynamics Laboratory
Building M-2, Montreal Road
Ottawa, Ontario
K1A OR6

1.0 INTRODUCTION

Aerobrakes of a simple design, consisting of rectangular plates hinged at the trailing edges of the blades, have often been incorporated into the control systems of Canadian Vertical Axis Wind Turbines (VAWT) for overspeed protection.

For example, the 230 kW Magdalen Islands VAWT has aerobrakes of this type located at the rotor equator. In this case, the hinge line is also located on the aerobrake centre line such that in the closed position one half of the aerobrake is held against the outward side of the blade and the other half trails behind the blade. The centre of gravity of the aerobrake is ahead of the hinge line so that centrifugal force acts to deploy the aerobrakes when they are released (i.e. the aerobrakes rotate about their hinge lines at the blade trailing edge until they are normal to the blade chord plane).

However, this design loses some of its effectiveness at low tip speed ratios when the blades experience high angles of attack and deep stalling. Therefore, other aerobrake configurations were investigated at the National Aeronautical Establishment (NAE) with a view to obtaining greater effectiveness at high angles of attack.

Flow visualization tests were carried out on two configurations and wind tunnel tests were carried out on three configurations.

This report provides a summary of the flow visualization tests, discusses the wind tunnel test procedure and presents the results of the wind tunnel tests in a non-dimensional form in order to allow a direct comparison of the various aerobrake configurations.

2.0 FLOW VISUALIZATION TESTS

Models of two aerobrake configurations were studied in the NAE Flow Visualization Water Tunnel using a two-dimensional NACA 0018 aerofoil of 15.75 cm chord to represent a typical blade section. One model simulated a configuration in which the aerobrakes are deployed on both sides of the blade with their common hinge line at or near the trailing edge of the blade. The aerobrakes were set at an angle of 80° to the blade chord plane and, most importantly, there was no slot in the blade created by the aerobrake deployment. In the deployed positon, this aerobrake configuration is aerodynamically very similar to the simple hinged flat plates used on the Magdalen Islands VAWT. (The only difference between the two is that the aerobrakes on the Magdalen Islands VAWT are at 90° to the chord plane when deployed.) The first model was therefore also representative of previous aerobrake designs.

For the second model, the slot in front of the aerobrakes was simulated by removing the trailing portion of the aerofoil at the 72.2% of chord position.

Figure 1 shows the first model at a high angle of attack, with a region of separated flow on the low pressure side of the blade completely engulfing the areobrake on that side.

Figure 2 shows the second model at a high angle of attack. A stagnation point is clearly visible on the aerobrake located on the positive pressure side of the aerofoil. Also, the slot allows a greater aerobrake area to be exposed to the impinging flow and therefore this configuration should be more effective.

These flow visualization experiments indicated that the slotted configuration would probably provide improved effectiveness over the conventional aerobrakes as represented by the first model. Therefore, in order to quantify the amount of improvement, wind tunnel tests were conducted on a series of models representative of these and other configurations.

3.0 WIND TUNNEL TESTS

A wind tunnel model was constructed by the NAE using an extruded aluminum NACA 0018 aerofoil of 61 cm chord. This model was tested in the NAE 2m x 3m Wind Tunnel in the following configurations:

(a) the model configured with aerobrakes and slots in the aerofoil, as shown in Figure 3;

(b) the same configuration with the slots blocked flush with the aerofoil outer surfaces;

(c) the model configured with aerobrakes perpendicular to the chord plane at the 30% of chord position (as shown in Figure 4) with the slots completely blocked flush with the aerofoil outer surfaces; and

(d) the model without any aerobrakes as a simple NACA 0018 aerofoil.

The configuration with the slots blocked was tested in order to provide a measure of the benefits created by the slots. This model configuration was geometrically similar to the flow visualization model of Figure 1. The model configured with aerobrakes at 30% chord was representative of spoilers which are often used on aircraft wings. This model was tested to provide data for comparison with the slotted configuration. Finally, the simple NACA 0018 aerofoil was tested in order to provide "base case" data from which relative changes due to the various aerobrake installations could be compared. A photograph of the model as a simple aerofoil mounted in the NAE 2m x 3m Wind Tunnel is presented as Figure 5.

The wind tunnel balance was used to determine the forces acting on the model. As shown in Figure 6, of prime interest to VAWT designers are the lift (L), drag (D) and the algebraic sum of their components along the chord line, known as the thrust force (T). A positive thrust force is defined as one which acts to push the blade forward and so in the evaluation of aerobrakes, the designer is looking for a configuration which creates the largest negative thrust over the widest range of angle of attack (α).

The data acquisition software written for these tests reduced all of these forces to standard coefficient form based on the plan view area (S) of the simple aerofoil (i.e. span times chord). The software also included a subroutine which corrected these coefficients for the effects of wind tunnel blockage caused by the presence of the model. The method used in this subroutine followed the Maskell blockage correction for bluff bodies (Reference 1). This correction method was selected, because all models, even the simple aerofoil, were tested over an angle of attack range of 0° to 180° and so at high angles of attack the model would be aerodynamically similar to a bluff body.

Wind tunnel balance data were recorded at angle of attack increments of 5° (i.e. 0°, 5°, 10°, 15°, ...).

The test Reynolds Number, based on the aerofoil chord, c, was 1.7×10^6.

4.0 ANALYSIS OF WIND TUNNEL DATA

In order to differentiate between the data for the models with aerobrakes and those of the "base case" aerofoil, the following symbols have been assigned:

(a) for the models configured with aerobrakes:

$$C_L' = \frac{L'}{1/2\rho V^2 S} \; ; \; C_D' = \frac{D'}{1/2\rho V^2 S}$$

$$C_T' = C_L' \sin\alpha - C_D' \cos\alpha$$

where C_L', C_D' and C_T' are the lift, drag and thrust coefficients, ρ is the air density, V is the velocity in the wind tunnel test section and α is the angle of attack;

(b) for the simple NACA 0018 aerofoil the same equations apply except that the primes are not used in order to indicate the absence of aerobrakes.

The thrust coefficient, C_T', can be used as a general indication of aerobrake effectiveness. However, in order to compare aerobrake configurations in a manner which accounts for the amount of aerobrake area deployed, the coefficients were modified as follows:

$$\Delta C_{LU} = \frac{C_L' - C_L}{A/S}$$

$$\Delta C_{DU} = \frac{C_D' - C_D}{A/S}$$

$$\Delta C_{TU} = \frac{C_T' - C_T}{A/S}$$

where A is the area of the aerobrakes.

These normalized coefficients, especially ΔC_{TU}, were then used to compare aerobrake configurations.

Figure 7 is a graph of ΔC_{TU} vs. α for each configuration. As can be seen from this graph, the two configurations with aerobrakes near the trailing edge maintain a negative ΔC_{TU} for a wider range of α than the configuration with aerobrakes at 30% chord. In fact, ΔC_{TU} for the configuration with open slots does not change sign until $\alpha = 137°$. While the aerobrakes at 30% chord are more effective (for a given area) at low angles of attack, they rapidly deteriorate in effectiveness as α increases. ΔC_{TU} for this configuration changes sign at $\alpha = 65°$. Over the range of 0° to 90°, the slotted configuration maintains a generally more negative value of ΔC_{TU} than the same configuration with closed slots. Since a negative value over a wider range of α, implies effectiveness over a longer sweep of the blade at low tip speed ratios, one concludes that the slotted configuration has a much more desirable characteristic.

Finally, it should be noted that the wind tunnel models had aerobrake to aerofoil area ratios as follows:

Slotted configuration: $\frac{A}{S} = 0.360$

Aerobrakes at 30% chord: $\frac{A}{S} = 0.403$

Thus the results given in this report will be applicable to geometrically similar aerobrakes of each type which have approximately the same area ratios.

5.0 CONCLUSIONS

Wind tunnel tests of three aerobrake configurations, intended for use in decelerating a VAWT, have been carried out in order to provide quantitative data for use in selecting aerobrakes for full size VAWTs. The analysis of the test data showed that one configuration had greater effectiveness than the other two. The most effective configuration was considered to be the one which maintained a negative thrust coefficient over the widest range of angle of attack.

6.0 ACKNOWLEDGEMENT

The author wishes to express gratitude to R.J. Templin, Head, Low Speed Aerodynamics Laboratory, NAE, for his guidance in the analysis of the wind tunnel data, and to the technical staff of the Laboratory who constructed all of the models and assisted in their testing: G. Dobrodzicki, D. Emmott, V. Maloney, T. Brown and J. Pye. Special thanks go to R. Dufault who produced the wind tunnel data reduction software.

7.0 REFERENCES

1. Maskell, E.C., A Theory of the Blockage Effects on Bluff Bodies and Stalled Wings in a Closed Wind Tunnel, British Air Research Committee R & M 3400, 1965.

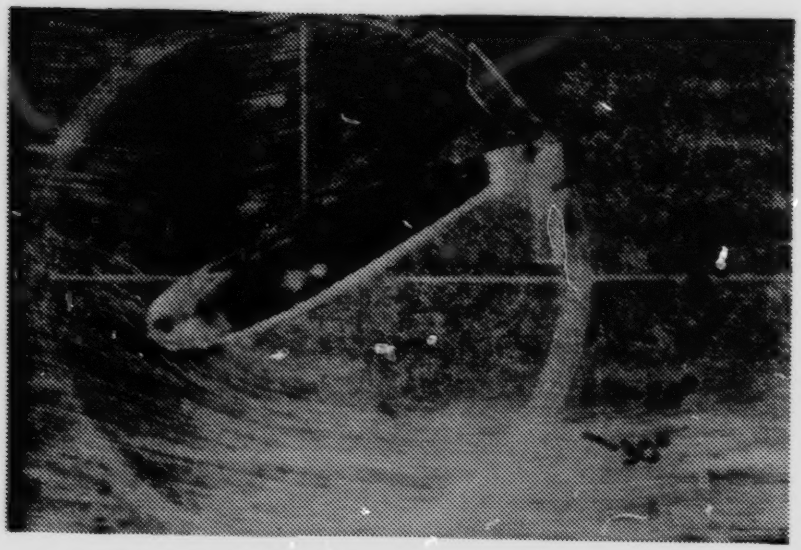


Figure 1. Flow visualization for aerobrakes deployed at trailing edge of NACA 0018 aerofoil; angle of attack = 29°

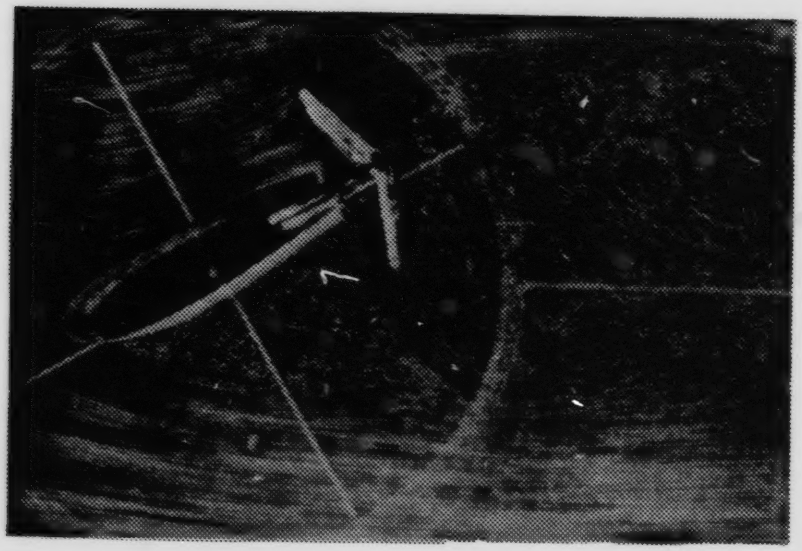


Figure 2. Flow visualization for aerobrakes deployed near trailing edge location of NACA 0018 aerofoil with simulated slot; angle of attack = 29°

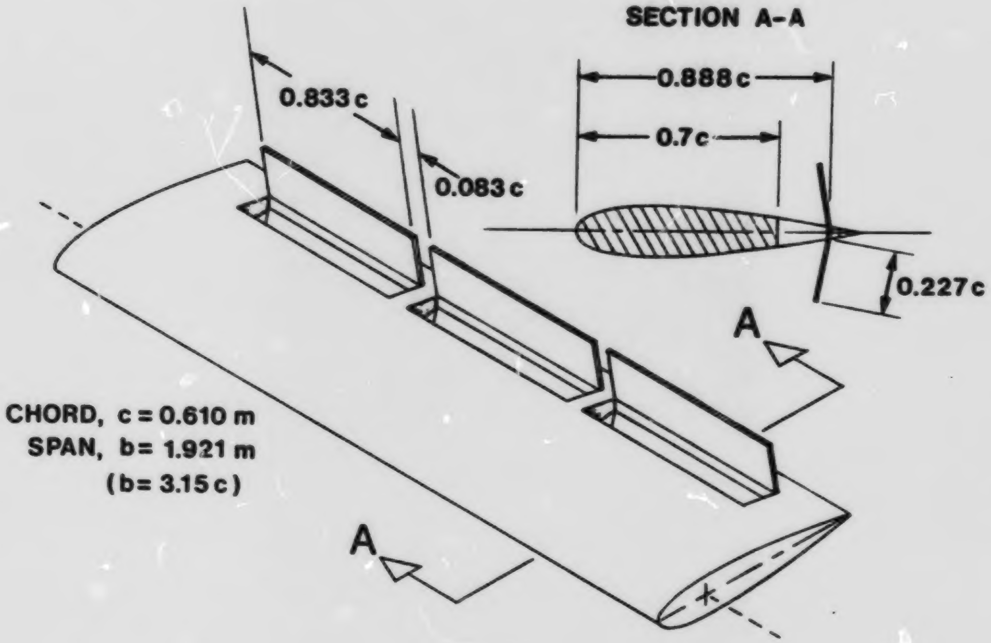

SECTION A-A
0.888 c
0.7c
0.833 c
0.083 c
0.227 c
A
A
CHORD, c = 0.610 m
SPAN, b= 1.921 m
(b= 3.15 c)

Figure 3. Wind tunnel model with aerobrakes and slots.

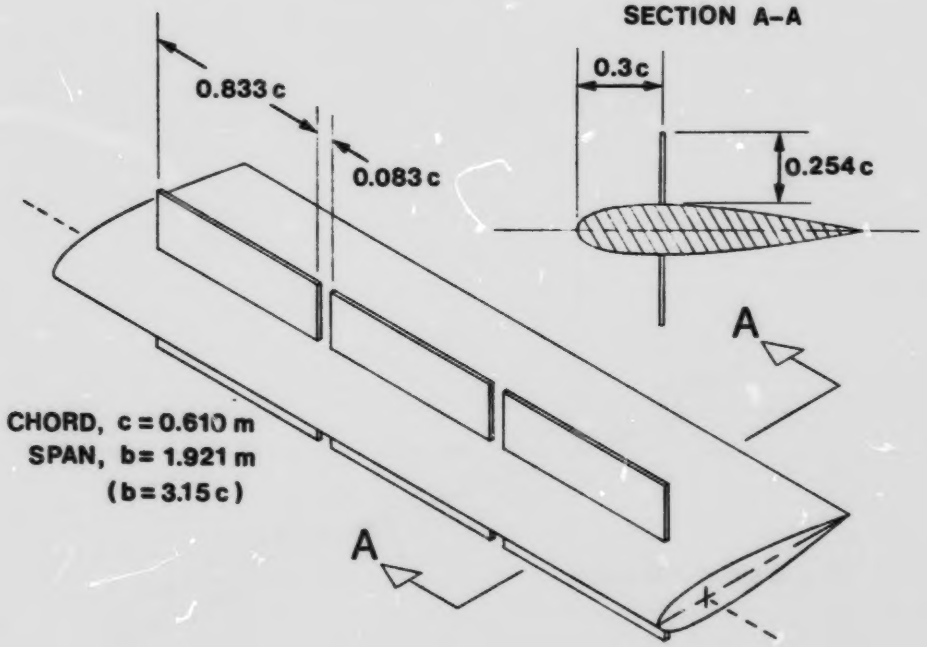

SECTION A-A
0.3c
0.833 c
0.083 c
0.254 c
A
A
CHORD, c = 0.610 m
SPAN, b= 1.921 m
(b= 3.15 c)

Figure 4. Wind tunnel model with aerobrakes at 30% chord.

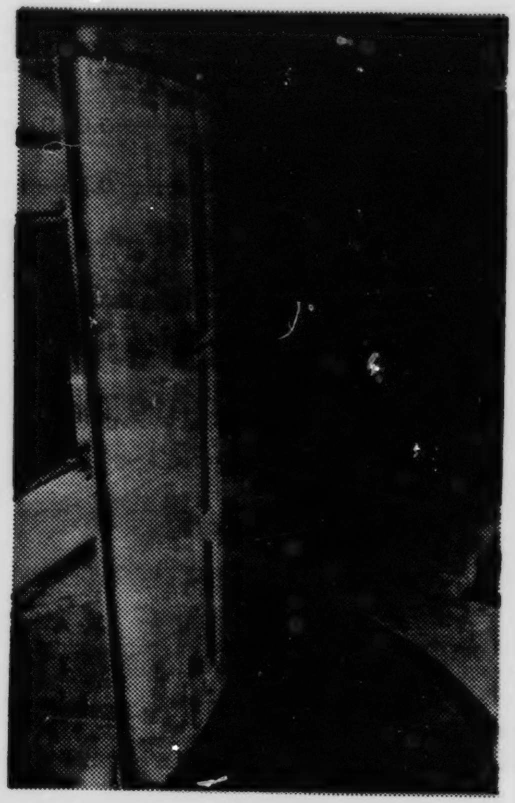


Figure 5. Model without aerobrakes mounted in NAE 2 m x 3 m Wind Tunnel

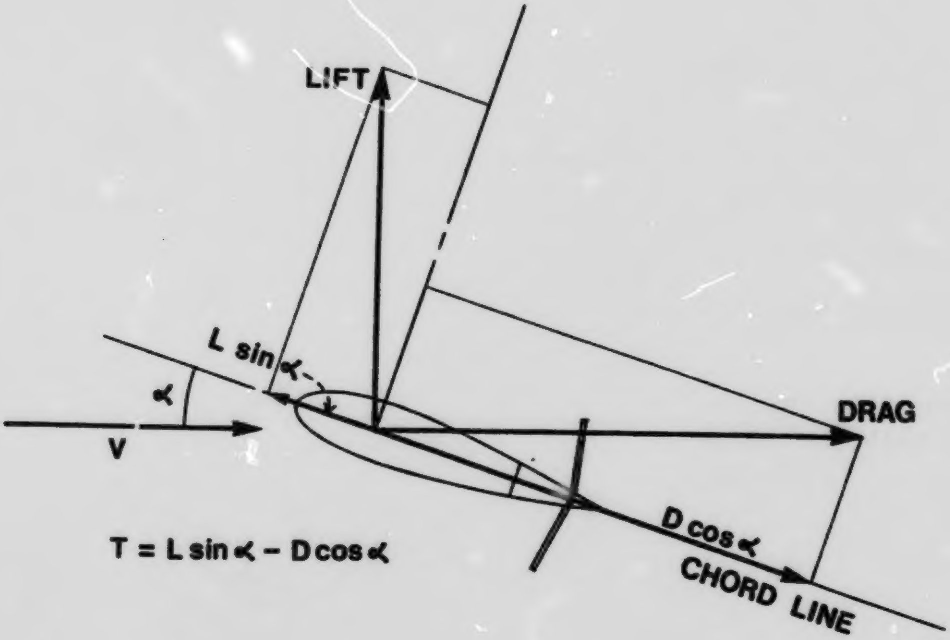

LIFT
L sin∝
∝
V
DRAG
D cos∝
CHORD LINE
T = L sin∝ − D cos∝

Figure 6. Definition of lift, drag and thrust forces on wind tunnel model.

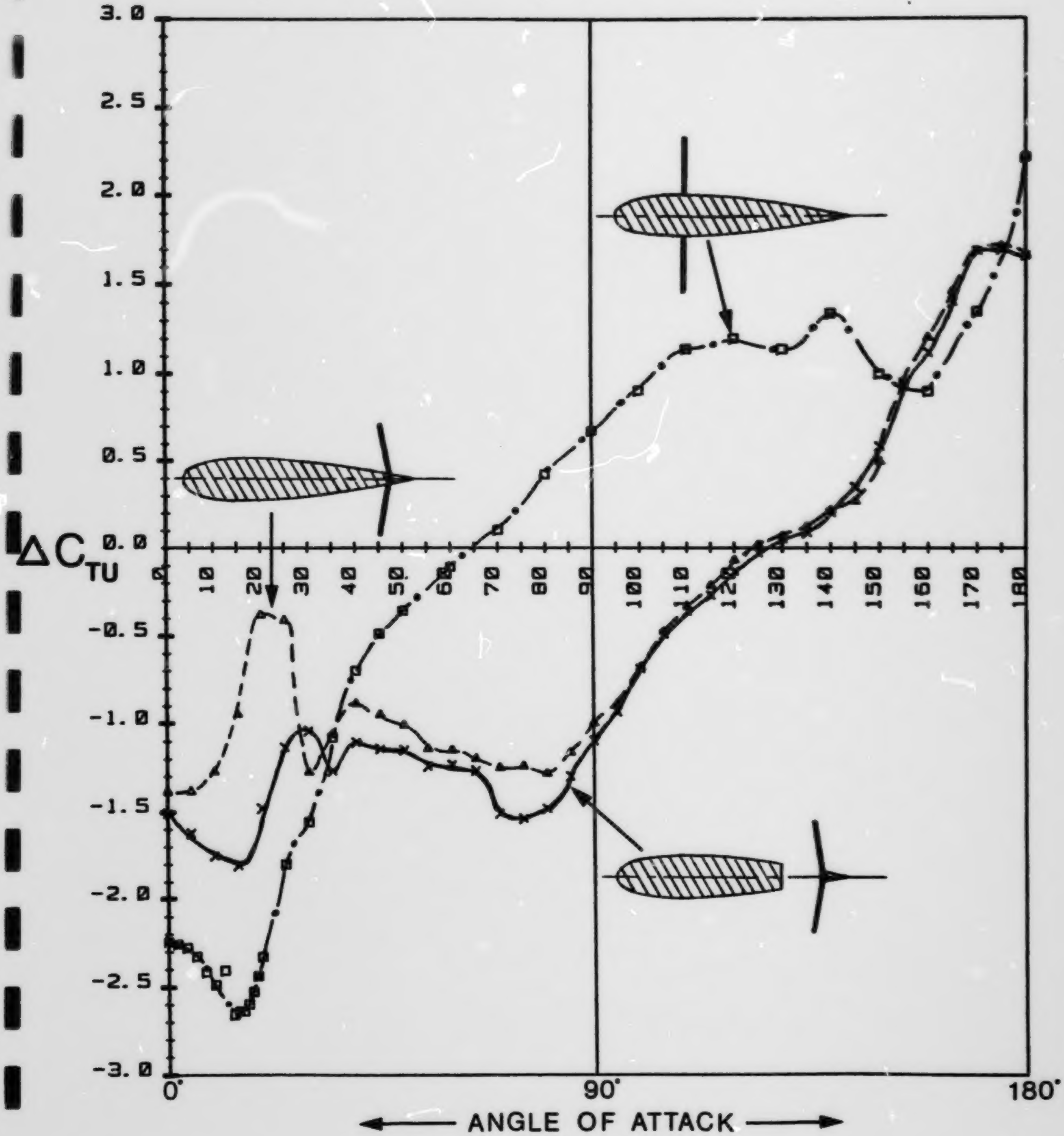


Figure 7. Aerobrake thrust coefficient vs. angle of attack.

WINDFARM COUPLING TO ONE DIESEL SET

Comparison between fixed pitch and Aerowatt-International variable pitch windturbines

-=-=-=-=-=-

Jean-Marc Noël,
Technical and Sales Manager

Aerowatt-International
6, avenue des Coquelicots

94385 Bonneuil Cédex

(France)

telephone : (Int'l : 33) 1 - 43 39 78 83
telex : 680 160 F AEROWAT

-=-=-=-=-=-

INTRODUCTION

The economic interest of coupling wind energy systems with classical electricity distribution networks consists, essentially, in substituting the cost of wind-produced kWh's for the marginal cost of producing those kWh's with traditional techniques and equipment. (Marginal cost of production : price of fuel delivered to the site per kWh, lubricating fluids, other consumables and incremental maintenance costs.)

Given the above truth, in order for wind energy systems to find a place in a market without specially designed tax incentives, it is necessary that the cost of the wind-derived kWh be less expensive than the per kWh cost of the above-mentioned consumables.

This inequality in costs is more easily observed as the cost of the fuel used increases, as in the case of diesel fuel which is the most expensive fuel widely used in the production of electricity.

This relative expensiveness of diesel fuel increases as the level of installed power generating capacity decreases.

Three major parameters dictate the increase :

- *Small volume deliveries of fuel tend to significantly augment the delivered cost of diesel fuel. (We are aware of several cases where fuel must be delivered in barrels whose replacement costs are appreciable components of the final cost.)*
- *The efficiency of small diesel generator sets is lower than that of larger installations (friction is relatively more important) and load variations are greater.*
- *Consumption of lubricating fluids is higher on a per kWh basis.*

In general, the competivity of wind-powered electricity is easier to establish in distribution grids powered by small diesel generator sets.

In this type of network, the electricity is provided by operating the generator at the central station whose output, while remaining superior, is nearest the existing demand. As demand increases, a more powerful machine is placed in service and the former generator set is shut down and vice versa. Observation over time of daily electricity consumption patterns has allowed these switchovers to be programmed fairly accurately.

In this way, in most small networks only one generator set is operating at any given time.

In the smallest networks, electricity producers, in some cases, completely shut down all generating capacity at times when extremely low load levels exist.

The overall situation described above leads to the following questions :

- *Can windgenerators be directly coupled with a diesel-based generating station ?*
- *What penetration level of wind-produced power is acceptable ?*

The following paper will describe that Aerowatt-International's windgenerators can be used to affirmatively answer the first question and that they also permit the installation of as much wind-based generating capacity as is deemed necessary and economically justifiable.

LIST OF FIGURES

- *Figure 1 : Fixed pitch windturbine Operating characteristics*
- *Figure 2 : Fixed pitch windturbine Regulation by the driven mechanism*
- *Figure 3 : Aerowatt variable pitch windturbine Operating characteristics P(f)*
- *Figure 4 : Fixed pitch windgenerator Adaptation using two generators*
- *Figure 5 : Characteristics of an Aerowatt windgenerator coupled to a fixed frequency electricity distribution grid*
- *Figure 6 : Characteristics of an Aerowatt windgenerator coupled to a variable frequency electricity distribution grid*
- *Figure 7 : Graphic depiction of the operation of a wind/diesel generating station at rated speed*
- *Figure 8 : Graphic depiction of the operation of a wind/diesel generating station :*
  - *with variable wind speeds,*
  - *with several windgenerators.*

LIST OF GRAPHS

- *AW 86.04.27/A : Measured characteristics of a 40 kVA diesel generator set*
- *AW 86.04.19/B : Aerowatt UM 70 windgenerators Rotating speeds of the rotor when operating without a load*
- *AW 86.04.27/B : Characteristics of the Leroy-Somer LS 160 M asynchronous generator*
- *AW 86.04.19/A : Aerowatt UM 70 windgenerators Rotating speeds of the rotor when coupled to a 50 Hz distribution grid*
- *AW 86.04.27/C : Aerowatt UM 70/10000/RES-LJ windgenerator. Characteristics with fixed and variable pitch rotors when coupled to a grid (F_{RES} 50 to 55 Hz)*
- *AW 86.03.07/AA : Operation of a diesel generator set coupled with an Aerowatt windgenerator*
- *AW 86.03.07/BA BC : Operation of a diesel generator set coupled with several Aerowatt windgenerators*

I - OPERATING CHARACTERISTICS OF A DIESEL GENERATOR SET ALONE

Let P_{GE} be the power delivered at the terminals of the generator with a rated power of P_{NGE}.

Let F_{GE} be the frequency of the current. For diesel generator sets on the market in the range of power which interests us (P_{NGE} > 30 kW), the generator is an alternator. F_{GE} will thus be equal, within an even multiple, to the frequency of the diesel motor.

The operating characteristic of the generator set is P_{GE} (f_{GE}).

This characteristics is quasi linear and defined by two points :

- *the rated value P_{NGE}, f_{NGE},*
- *the value when operating without a load P_{OGE}, f_{OGE}.*

In the range of power which interests us and for standard equipment, the regulation of operating speed is accomplished by a centrifugal regulator. With such equipement $f_{OGE} > f_{NGE}$.

We will call stability of the diesel generator set, the quantity $s\ \% = \frac{f_{OGE} - f_{NGE}}{f_{NGE}} \times 100$

Standard characteristics

For diesel generator sets of several dozen kW, the stability is of the order of 4 to 5 %.

The graph AW 86.04.27/A represents the measured operating characteristics of an ordinary diesel generator set (construction site type, rated power 40 kW, equipped with 6 cylinder Ford GB diesel motor). During the measurements, we also recorded the operating frequency of this generator set when power was being sent back into the generator and the diesel motor was operating as a compressor.

In these conditions :

- *s generator : 6,40 %*
- *s compressor : 15,50 %*

-o-o-o-o-o-

II - CHARACTERISTICS OF AN INDEPENDANT WINDTURBINE

The windturbine consists of the rotor and the transmission which is normally part of its configuration, without the machine that is being driven by the windturbine.

21.- Fixed pitch rotor

In the field of frequency/power, each rotor is defined by a grid of characteristics P_{Vi} (f_{HE}), under constant wind velocity V = Vi.
In figure 1 are shown several of these characteristics.

In ideal operation, i.e., at variable wind speeds the curve which envelops all possible values under constant wind velocity, is P_M (f_{HE}), the maximum power characteristic.

[This curve is also the locus of the finite aerodynamic stalling points. With the characteristics P_{Vi} (f_{HE}), when the frequency decreases below the values defined by the curve P_M (f_{HE}), stalling occurs and an abrupt loss of power is provoked.]

It appears that without adding a specially adapted load to the fixed pitch rotor there is neither auto-limitation of rotational speed nor power, which increases with accelerating wind speeds.

The P_M (f_{HE}) characteristic has a steep, positive slope : an increase in frequency brings with it a significant increase in supplied power. [Moreover, the segments of P_{Vi} (HE) corresponding to the stalling have an higher slope.]

All winds stability and rotational speed control for stand alone windturbines equipped with fixed pitch rotors is accomplished by using a load whose characteristics shows a slopeeven steeper than P_M (f_{HE}) or than P_{Vi} (HE) area involved (see figure 2) when running.
For V = V_{M+}, the operating value is located at the intersection of the P (V_{M+}) characteristic and of the load characteristic (A). Considering the slopes in relation to point M, this point is located in the "stalled" portion of the characteristic. This operating point N corresponds to a power level less than that obtained at M.

It follows from the conditions of speed limitation for fixed speed rotors that they will "run away" if the load being used no longer absorbs power. It is necessary to equip fixed pitch windgenerators with brakes capable of stopping the machines when torque has reached maximum levels.

22.- Aerowatt-International variable pitch rotors

Up to point M the operation of Aerowatt-International variable pitch rotors is identical to that of fixed pitch rotors.

Point M corresponds to F_{RAW}, which is the frequency at which the Aerowatt rotor is regulated. Above this frequency, the change of pitch brought about by the action of centrifugal force causes a decrease in the power being supplied proportional to the increase in frequency. When the frequency reaches F_{OAW}, at which point the turbine is operating without a load, no power is being delivered (see figure 3).

In reality the frequency F_{OAW} varies with wind speed and the blade profile being used as is shown in the graph AW 86.04.19/B.

-o-o-o-o-o-

III - OPERATING CHARACTERISTICS OF WINDGENERATORS COUPLED TO FIXED FREQUENCY GRIDS

31.- Asynchronous generators

The great majority of windgenerators installed in grid-coupled configurations are equipped with asynchronous generators. The fundamental attraction of these machines is that their own voltage is close to zero at the moment of coupling which eliminates the need to match phases at coupling.

Coupling can be accomplished "in flight", when the frequency of the windgenerator is within a "window" centered on the grid frequency.

The asynchronous generator is a generator which supplies power proportional to its relative slip, g ; i.e., to the difference between its mechanical frequency, F_{ME} when it is driven by a windturbine rotor, and the grid frequency F_{RES} :

$$g\ \% = \frac{F_{ME} - F_{RES}}{F_{RES}} \times 100$$

Standard model asynchronous generators deliver their rated power at a slip of approximately 3 %.

The graph AW 86.04.27/B shows the measured characteristics of a standard asynchronous generator.

32.- Fixed pitch windgenerators

The 3 % slip of standard asynchronous generators renders them well suited for use as electricity generators associated with fixed pitch rotors. Autoregulation of rotational speed is completely ensured if the grid can absorb all the power delivered by the windgenerator.

The limited slip of asynchronous generator (induction motor) does not allow to maintain maximum efficiency when wind velocity changes from the adaptation one. This draw back is mainly evident at low wind speeds when available energy is few.
[P_M (f_{ME}) exhibits the maximum available power but with poor η (efficiency). Maximum η locus is a curve parallel to P_M (f_{ME}) but lying under.]
A widely used remedy to this situation is to use two generators in each windturbine : one for low wind speeds and another for medium to high wind speeds.
The first generator is driven at a higher gear ratio than the second. In low wind speeds the fixed pitch rotor will rotate more slowly than at medium to high wind speeds. This is illustrated in figure 4.
At a predetermined power level the smaller generator (G2) is uncoupled, the rotor accelerates and the larger generator (G1) is coupled.

33.- Aerowatt-International windgenerators

Aerowatt-International also uses asynchronous generators in grid connection applications.

In order to deliver their rated power, these generators must be driven by a rotor/gearbox combination whose frequency $f_{NAW} = f_{RES}\,(1+g)$.

The operating characteristic of an Aerowatt-International windgenerator coupled to a grid, whose frequency is f_{RES}, is the segment (M - f_{RES}) figure 5.

Graph AW 86.04.19/A shows the rotational speed of the rotors of UM 70/RES windgenerators coupled to a 50 Hz grid [N/50 Hz = 214.3 rpm].

The differences between the two characteristics comes from the different performances of the blade profiles used :

- Göttingen 548 for the wooden blades (PB),
- Naca 23-021 for the wood/epoxy blades (LJ).

-o-o-o-o-o-

IV - COUPLING TO A VARIABLE FREQUENCY GRID

41.- Fixed pitch windgenerators

As was indicated in paragraphe 32. above, the rotational frequency of the rotor is tightly correlated to the grid frequency by the slip of the asynchronous generator. If the frequency of the grid increases, the rotor frequency increases also slightly and the characteristics of the machine change.

This is illustrated in graph AW 86.04.27/C which shows the power characteristics of an Aerowatt UM 70/10000/RES-LJ windgenerator equipped with a fixed pitch rotor and coupled to a grid whose frequency varies from 50 to 53 Hz.

There are no particular problems, however, the maximum power increases from 18.2 kW at f_{RES} = 50 Hz to 21.8 kW at f_{RES} = 53 Hz. This 19.8 % increase in maximum power needs to be considered when dimensioning the asynchronous generator.

42.- Aerowatt variable pitch windgenerators

The regulation frequency of the variable pitch rotor having been adjusted in such a way that rated power is delivered to a 50 Hz grid when f_{OAW} = 53 Hz ; thus, when the grid frequency increases the slip will decrease. This is illustrated in graph AW 86.04.27/C where we see that the power transferable to the grid by the UW 70/10000/RES-LJ, equipped with a variable pitch rotor, will decrease toward zero as the grid frequency increases from 50 to 53 Hz.

This phenomenon is shown in a more synthesized manner in figure 6. The power transferable to the grid as a function at grid frequency is defined by the function $P(f_{RES})$.

This function is characterized by a high negative slope.

-=-=-=-=-=-

V - COUPLING TO AN ISOLATED DIESEL GENERATOR SET

51.- Fixed pitch windgenerators

Without special precautions, coupling a fixed pitch windgenerator to an isolated diesel generator set results in an unstable operating condition.

From the preceeding analyses, we have seen that the power characteristics of fixed pitch windgenerators as a function of f_{RES} show a steep, positive slope (that of the associated asynchronous generators). The power they will deliver to the grid will increase as the frequency of the diesel generator set increases and the power it furnishes decreases. In situations of accelerating wind speeds this cumulative phenomenon will lead to a total transfer of deliverable power to the windgenerators and to continuing acceleration in their rotational speed.

Such coupling is only possible when :

- the combined rated power of the windgenerators is only a fraction of the rated power of the diesel set,

- additional loads can automatically be connected to the grid to maintain a stable frequency when load dwindles or desappears.

52.- Aerowatt variable pitch windgenerators

The steep negative slope which characterises the delivered power function of Aerowatt variable pitch windgenerators when coupled to a grid of variable frequency renders their coupling to an isolated diesel generator set perfectly stable.

521.- Graphic dediction of a hybrid wind/diesel system

5211.- At stable wind speed (V = Vc)

Assumptions

The isolated diesel generator set has the following characteristics :

> rated power P_{NGE}, rated frequency f_{NGE},
> frequency without a load f_{OGE}.

The windgenerator (or windfarm) has a rated power of P_{NAW} at f_{NGE} and gives no power at f_{OAW}

The system is represented in figure 7.

The characteristic of the system is shown by the $P_{SY}(f)$ curve.

For a load "I", the operating point will be A.

For a load "J", the operating point will be B. In this situation power is being sent back into the diesel set.

This operation is illustrated by the recording which shows the operating conditions of such a system in graph AW 86.03.07/AA.

$$P_{NGE} = 40\ \text{kW},\ \begin{cases} f_{NGE} = 49.4\ \text{Hz} \\ f_{OGE} = 52.74\ \text{Hz} \end{cases}$$

$$P_{NAW} = 17\ \text{kW},\ \begin{cases} f_{NAW} = 51.5\ \text{Hz} \\ f_{OAW} = 54.1\ \text{Hz} \end{cases}$$

5212.- At variable wind speeds

See figure 8.

The V axis is denominated in wind speeds :

- at A, the wind speed is equal to Vci, "cut-in" speed,
- at N, the wind speed is the rated speed, Vn,
- at B and C, intermediate values are shown.

For clarity in the illustration, the characteristic of the windgenerator has been assimilated to the straight segment Paw(V).

The above-noted situation, "2" and "3" are found on the AW 86.03.07/AA graphic recording.

5213.- Multi-machine windfarm

See figure 8.

The V axis can now be denominated as the number of windgenerators coupled to the diesel set; if there are three windgenerators :

- at A, no windgenerators are coupled,
- at B, one windgenerator is coupled.
- at C, two windgenerators are coupled,
- at D, three windgenerators are coupled.

In this system, if the user decides to prevent returns of power toward the diesel set, an automatic, management controller will decouple a windgenerator in order to maintain some load on the diesel set. This is the situation represented for the power level "3" in which case the maintenance of 3 windgenerators coupled to the grid would provoke a return of power toward the diesel set. The uncoupling of a windgenerator is indicated as well as the evolution from condition N to condition C.

This is illustrated by the reproduction of the recording AW 86.03.07/B which shows such uncouplings.

-o-o-o-o-o-

VI - CONCLUSION

The mastery of the operating stability of a wind/diesel hybrid system using Aerowatt-International variable pitch windgenerators as described above makes it possible to have no limit on the wind energy component in such a system.

Any limitation will be the result of strictly economic, and not technical, considerations.

As a function of the relative cost of the wind-produced kWh and the marginal cost of diesel-based generation at the site being considered, users can, in effect, choose the amount of installed wind energy capacity within the following two limits :

- wind derived power = base load ; in this case all the wind power will be used,

- wind derived power > peak load ; in this way, by considering local wind regimes, diesel fuel consumption can be minimized.

The simulation of such a hybrid system is relatively simple to carry out and allows a fairly close predetermination of the most economical configuration for the hybrid generating plant.

-o-o-o-o-o-

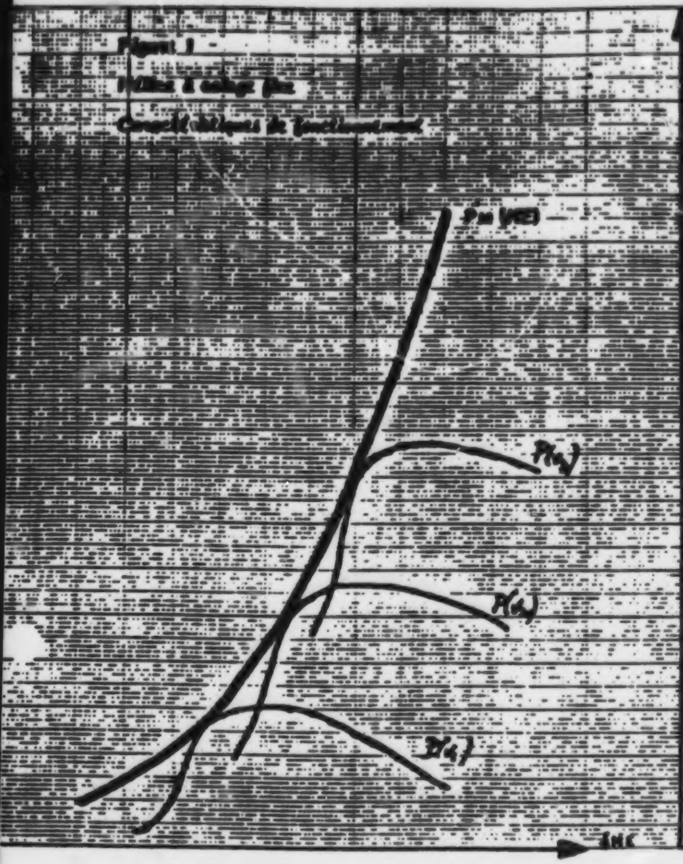


Figure 1

Hélice à calage fixe

Caractéristiques de fonctionnement

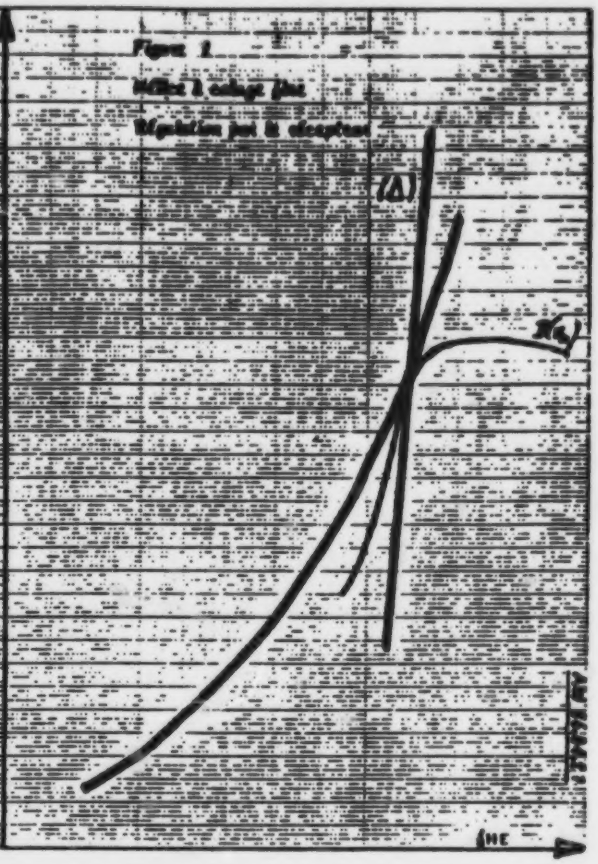


Figure 2

Hélice à calage fixe

Régulation par le décrochage

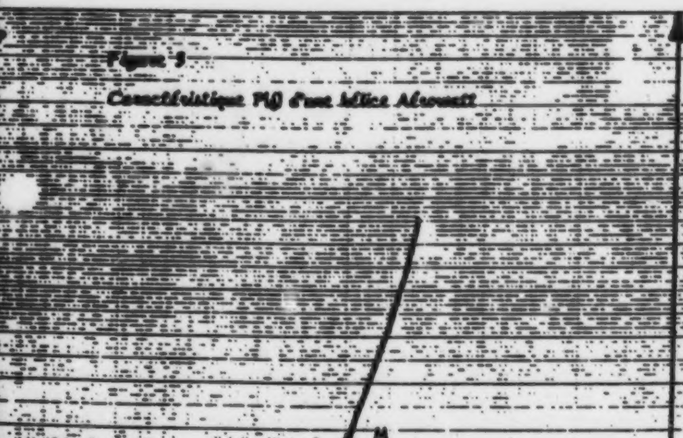


Figure 3

Caractéristique P(Ω) d'une hélice Aérowatt

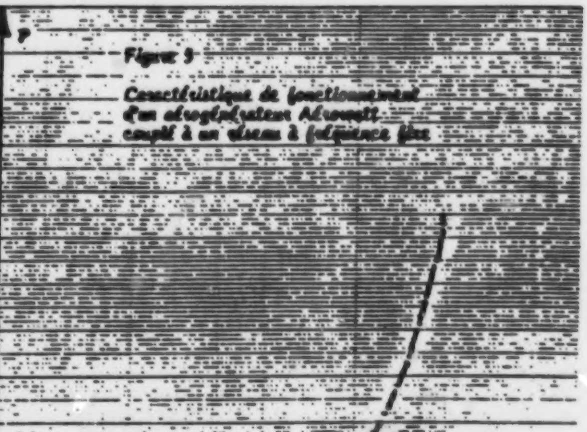


Figure 3

Caractéristique de fonctionnement
d'un aérogénérateur Aérowatt
couplé à un réseau à fréquence fixe

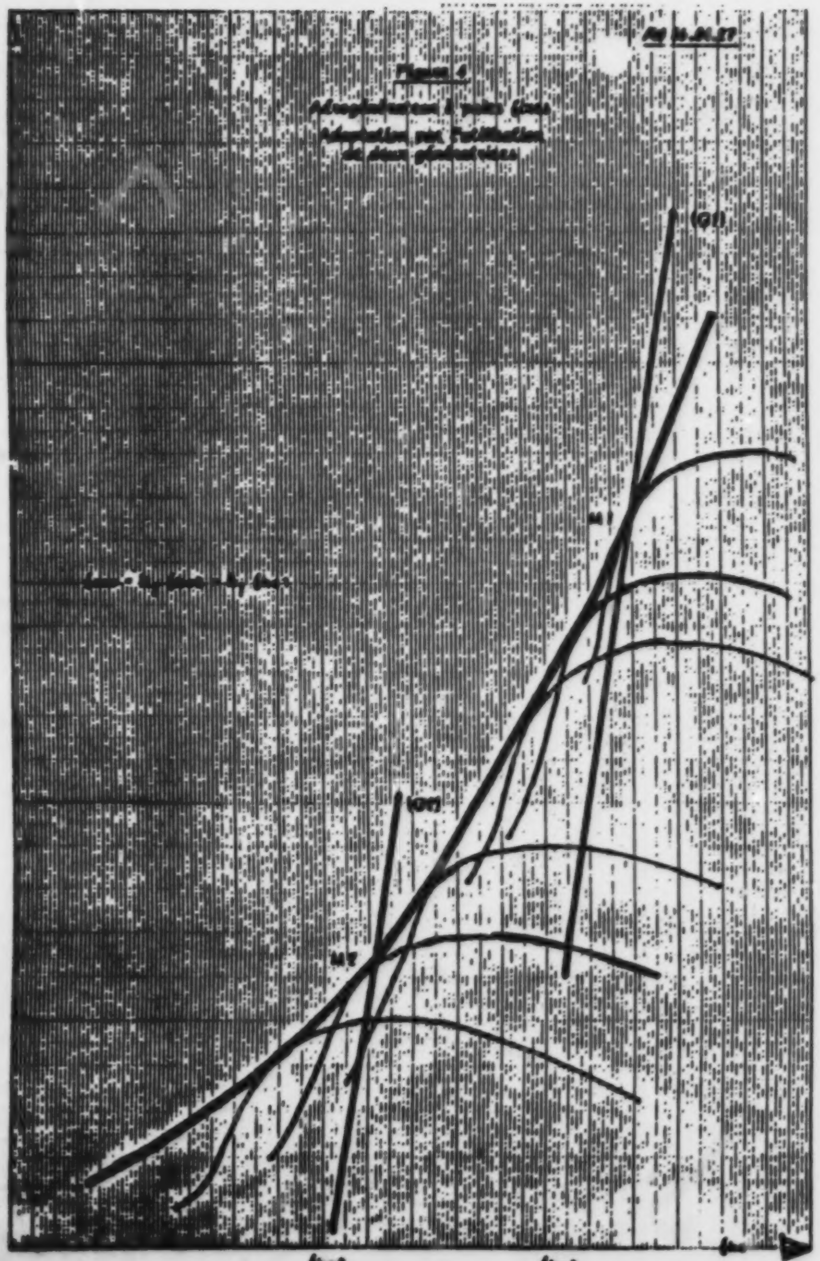


Figure 4

Aérogénérateur à pales fixes
Adaptation par l'utilisation
de deux génératrices

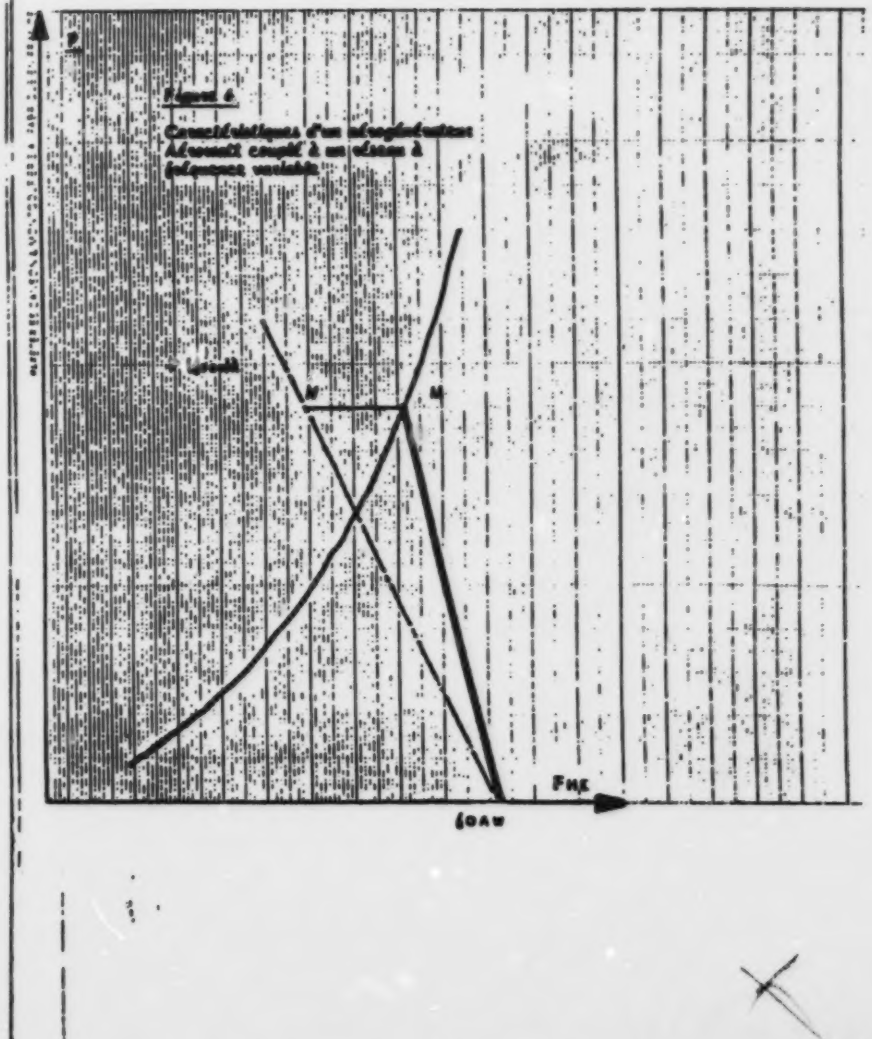
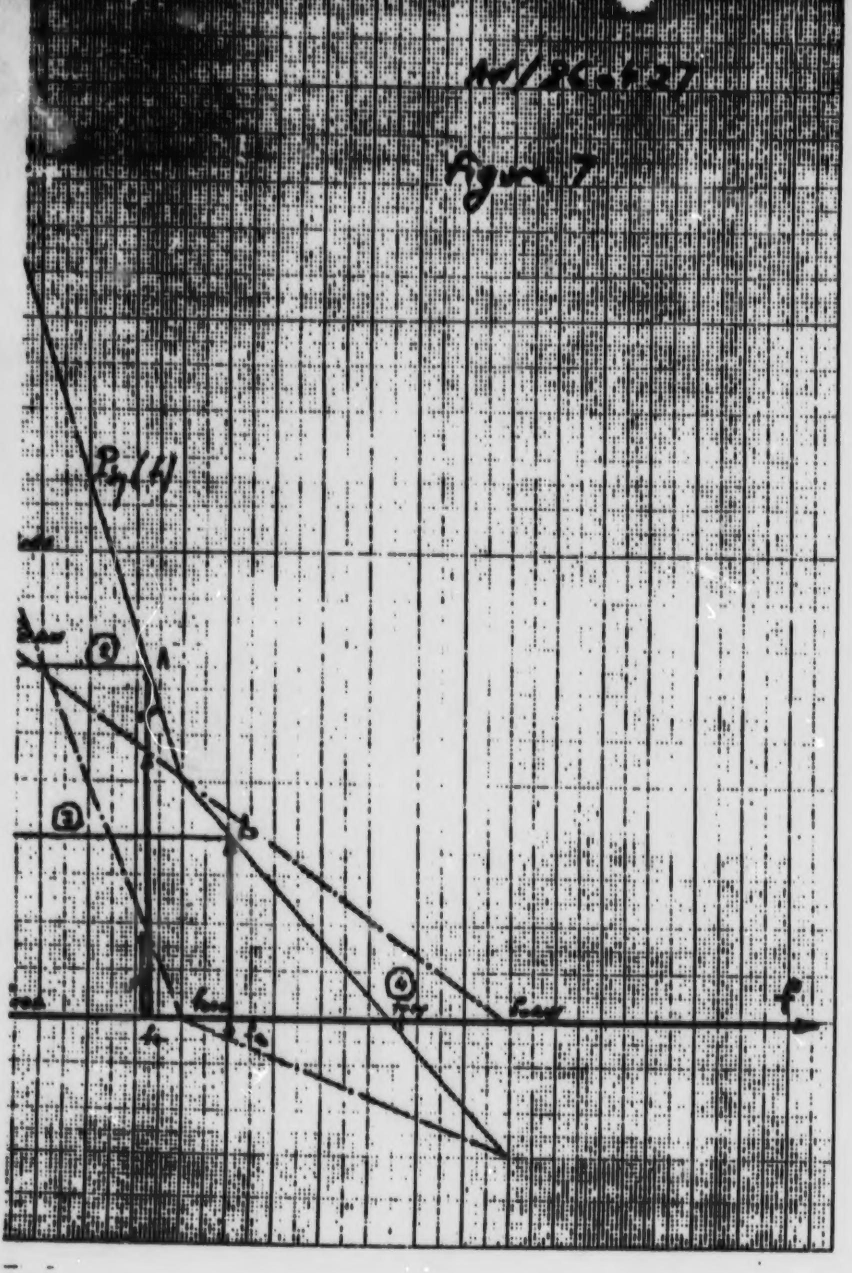


Figure 6

Caractéristiques d'un aérogénérateur
[illegible] couplé à un réseau à
fréquence variable



M/SC.4.27

Figure 7

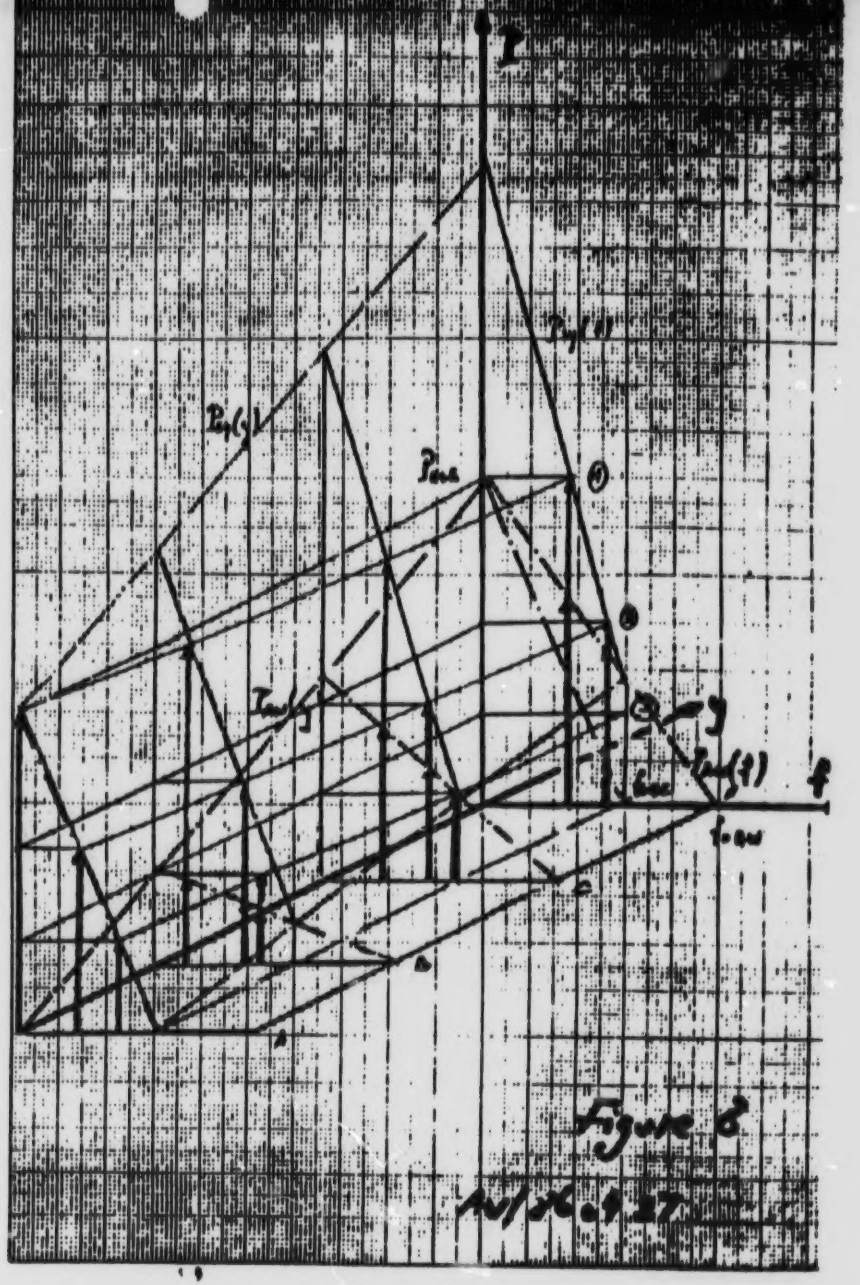
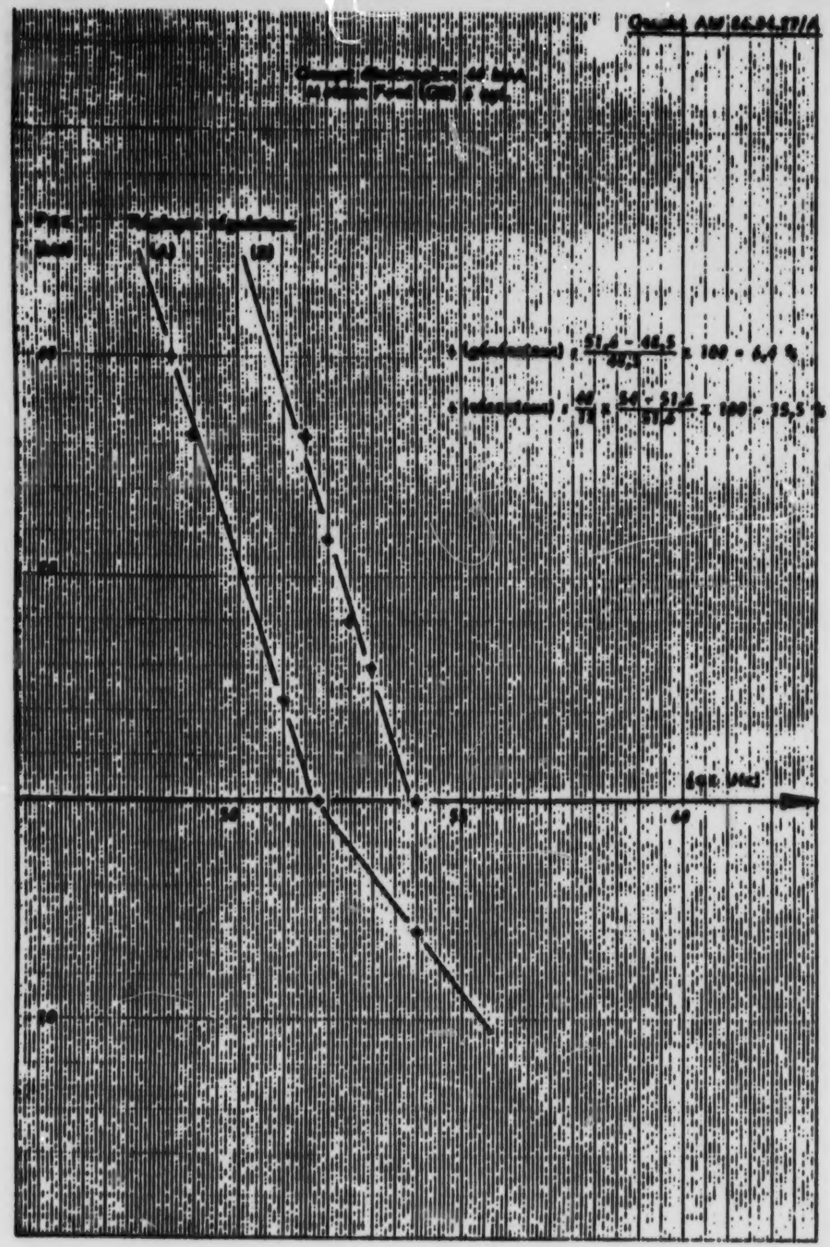
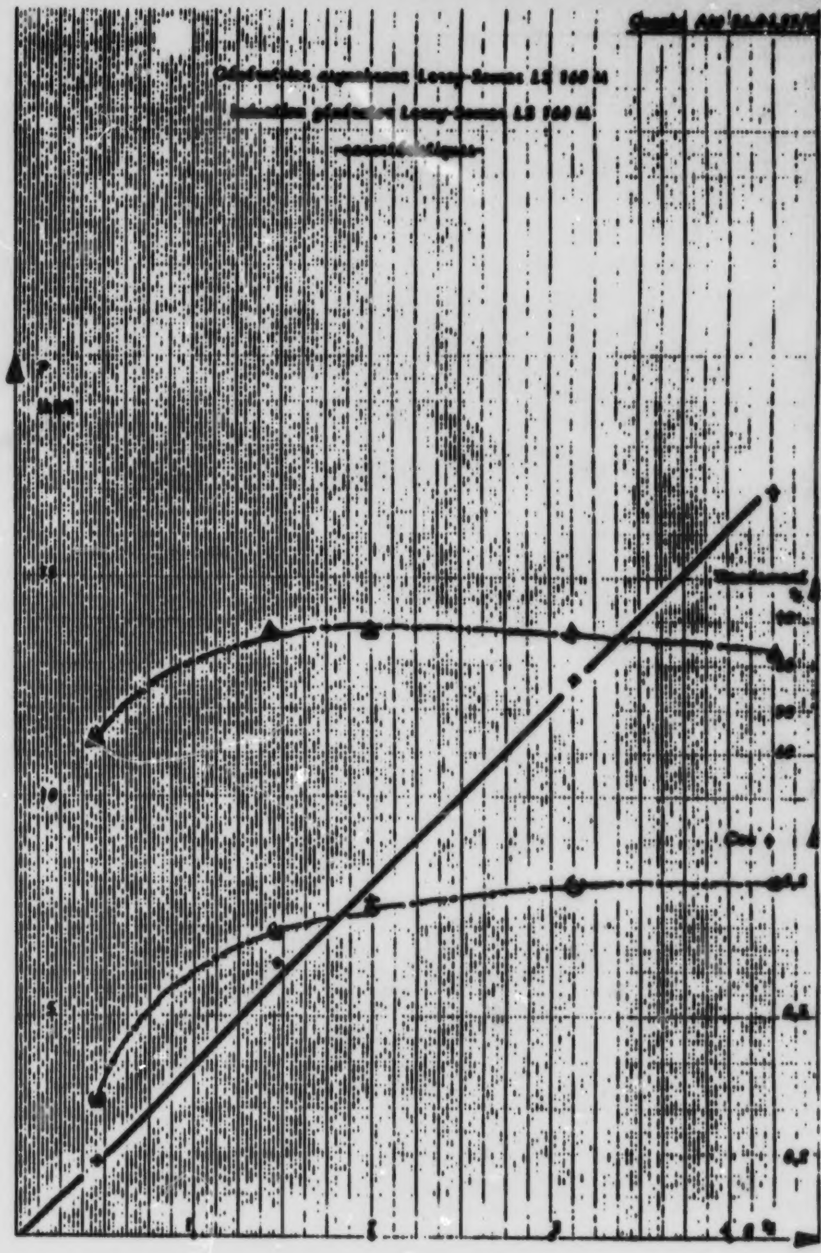

P
f
$P_{sy}(t)$
$P_{sy}(y)$
P_{out}
①
②
③
$T_{out}(y)$
$T_{out}(t)$

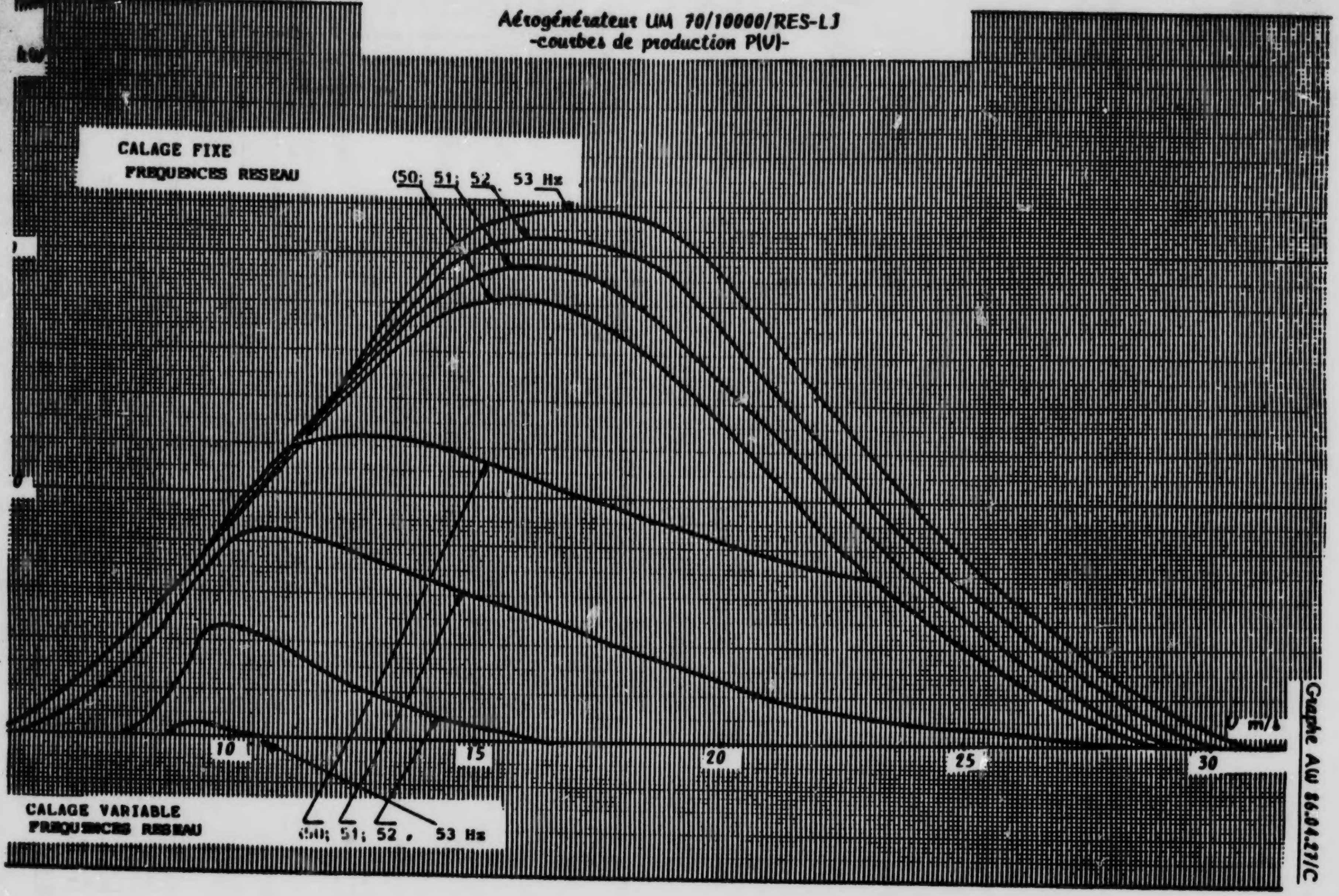
Figure 8

AV/SC.4.27


(A)
(B)
50
55
60


LS 160 M
LS 160 M
1
2
3
5
10
15
0,5

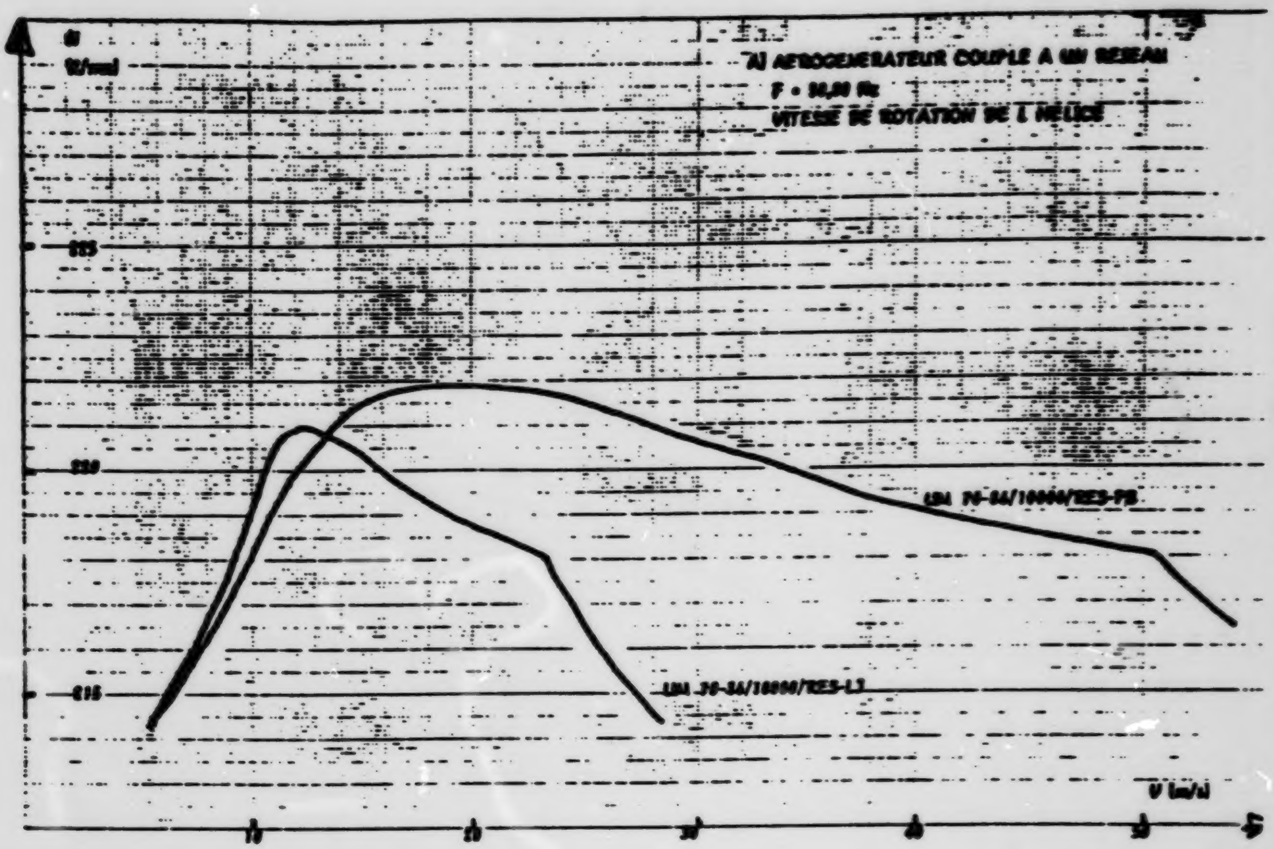
Aérogénérateur UM 70/10000/RES-LJ
-courbes de production P(V)-

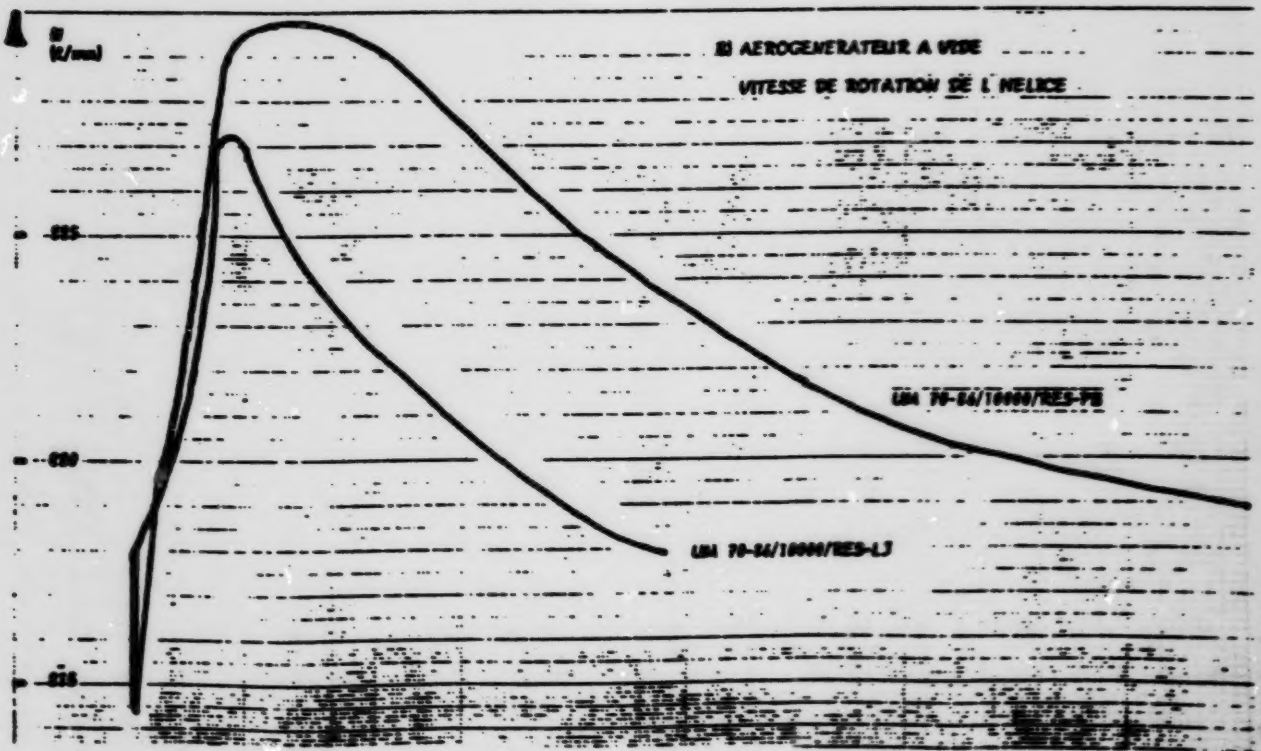


Graphe AW 86.04.27/C

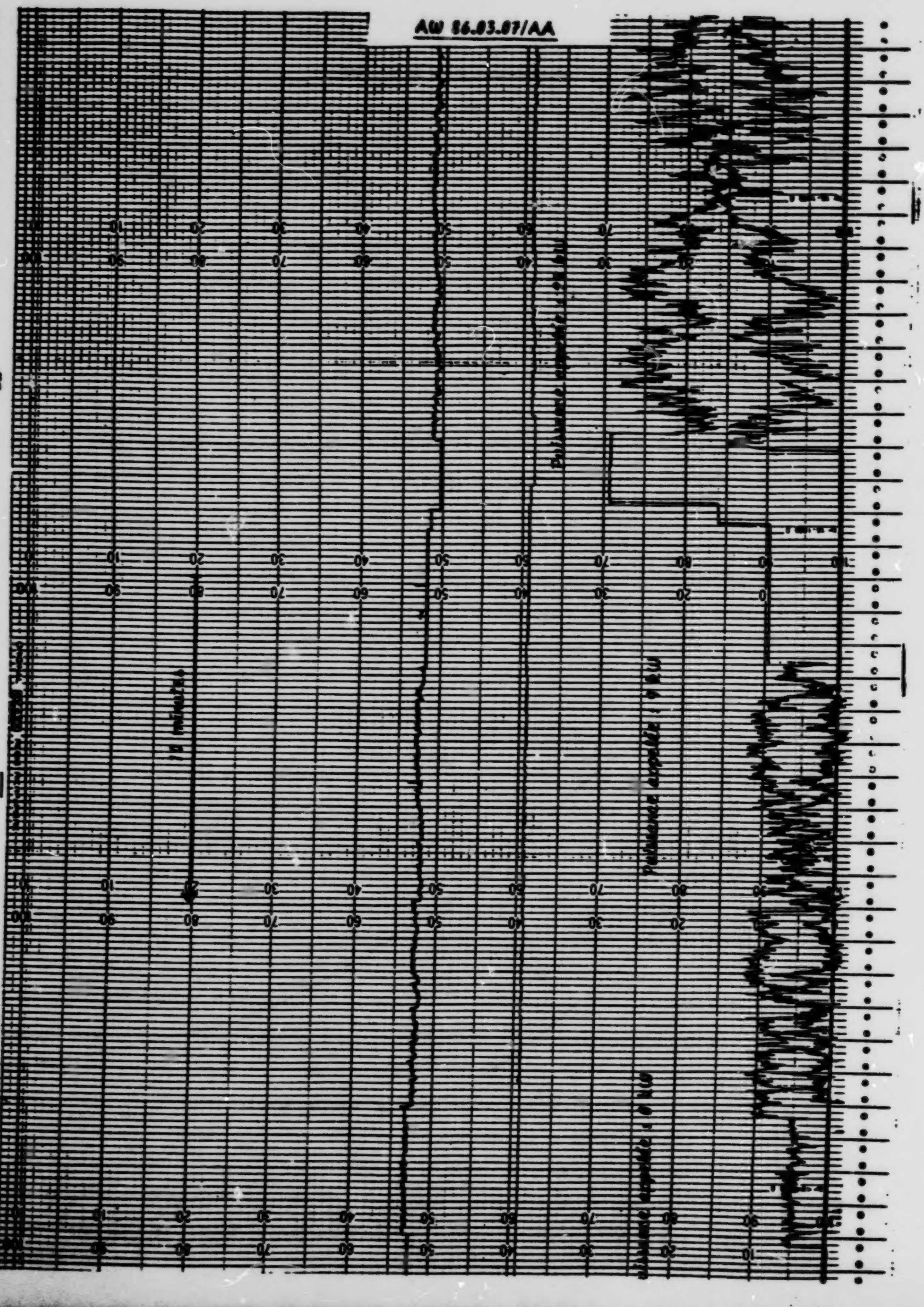
AW 86.04.19

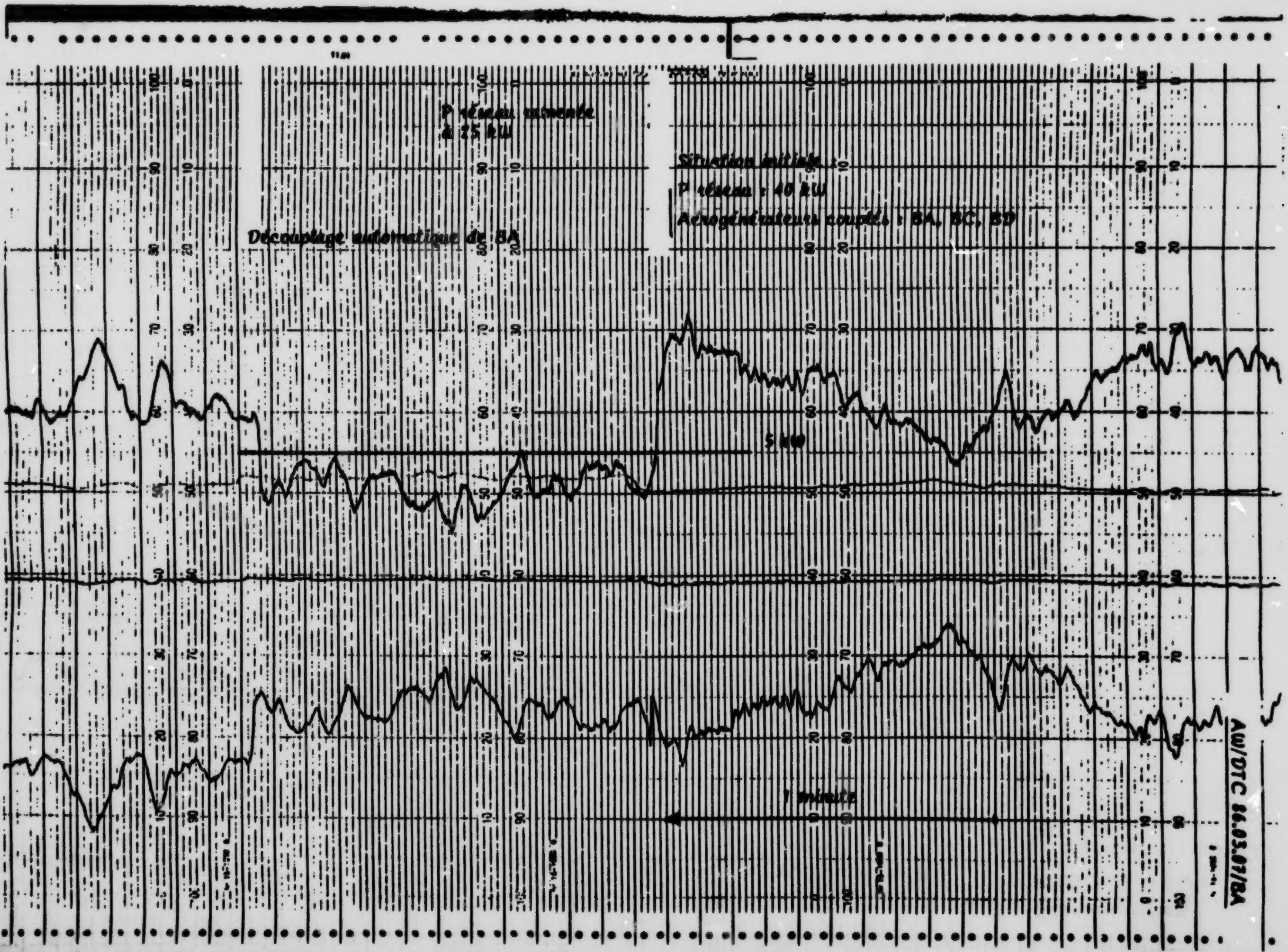
Aérogénérateurs UM 70-86/10000/RES

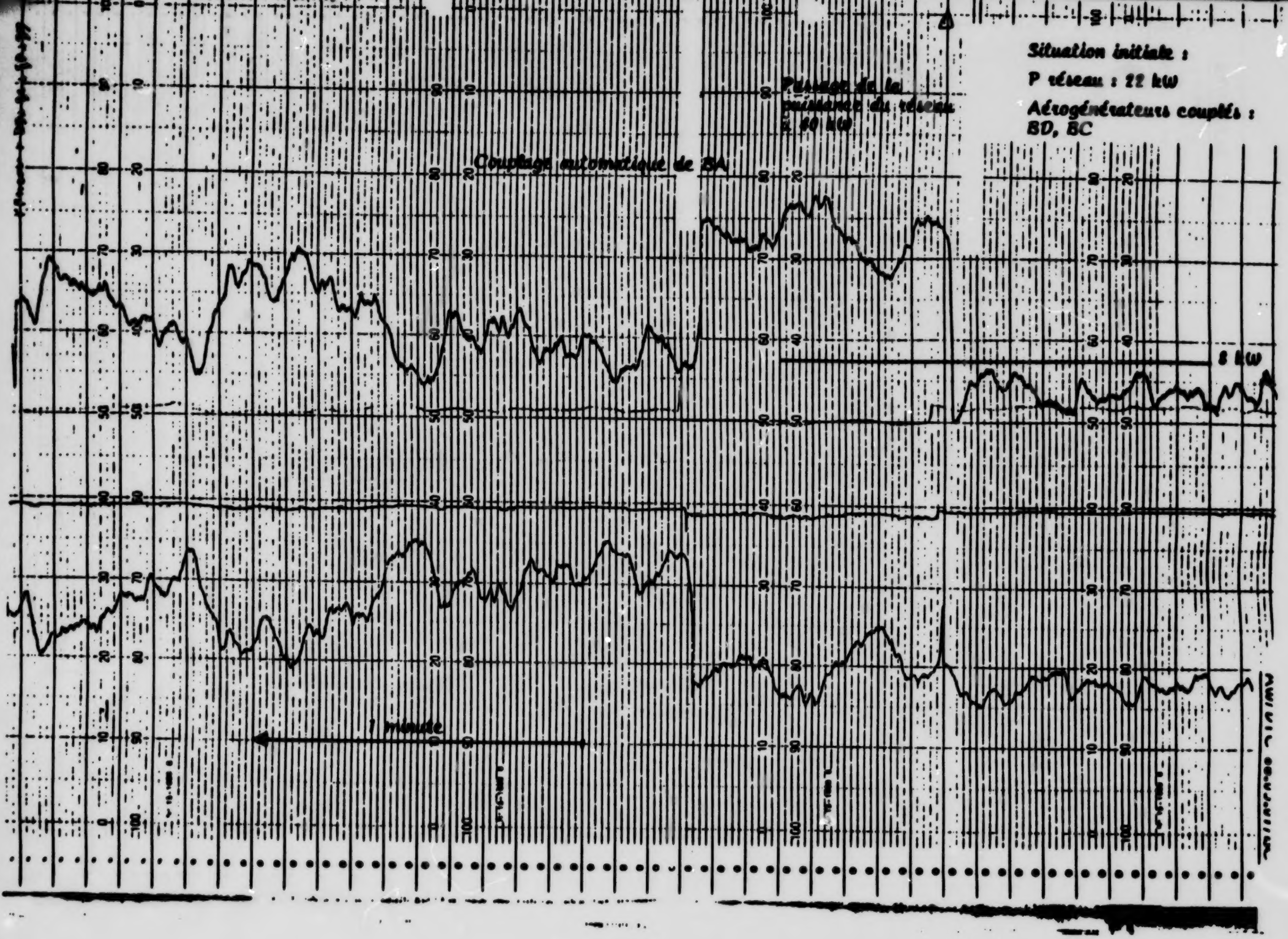




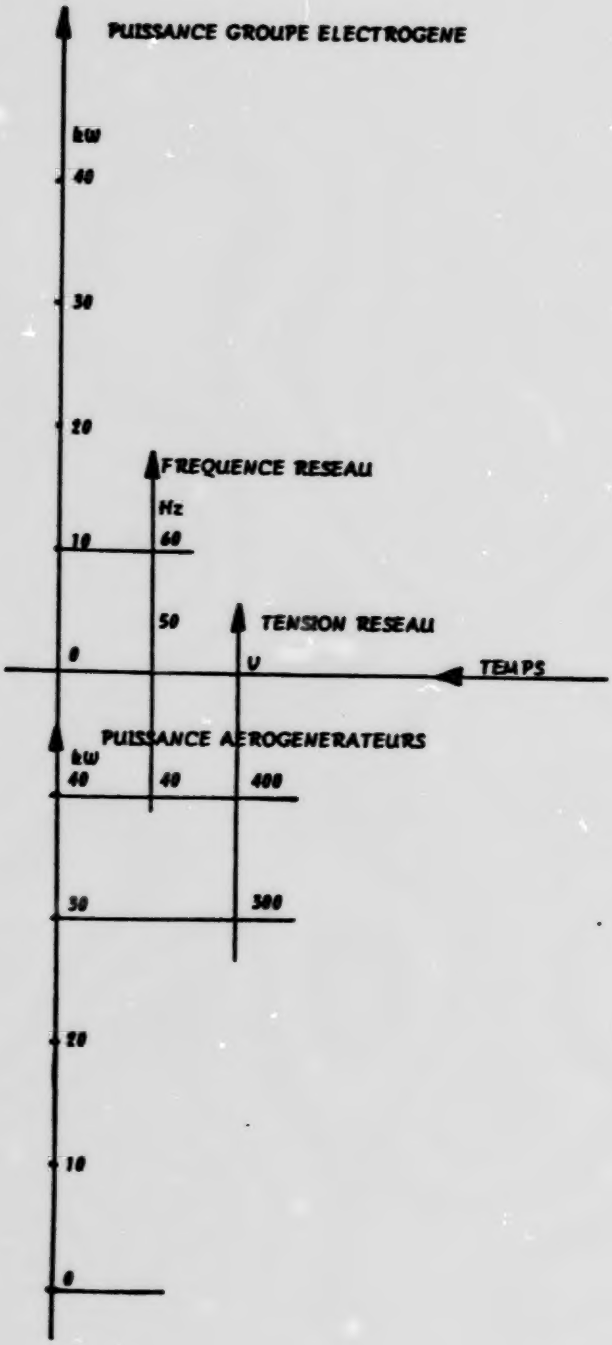
AW 86.03.07/AA


10 minutes
Puissance appelée : 9 kW
…issance appelée : 6 kW
Puissance appelée
0
10
20
30
40
50
60
70
80
90
100


P réseau augmenté à 25 kW
Découplage automatique de BA
Situation initiale :
P réseau : 40 kW
Aérogénérateurs couplés : BA, BC, BD
5 kW
1 minute
AW/DTC 86.03.07/BA


Situation initiale :
P réseau : 22 kW
Aérogénérateurs couplés : BD, BC
Passage de la puissance du réseau à 40 kW
Couplage automatique de BA
8 kW
1 minute
0
10
20
30
40
50
60
70
80
90
100

Grille d'identification et d'échelle des enregistrements


PUISSANCE GROUPE ELECTROGENE
kW
40
30
20
10
0
FREQUENCE RESEAU
Hz
60
50
40
TENSION RESEAU
U
400
300
TEMPS
PUISSANCE AEROGENERATEURS
kW
40
30
20
10
0

WIND ENERGY STANDARDS

CSA STANDARDS PROGRAM ON WIND ENERGY

BRIAN WEIR

CANADIAN STANDARDS ASSOCIATION

The purpose of speaking to you today is to give you a brief update on the standards program since last year's conference was held.

I am pleased to report that good progress has been made on various fronts in the standards program during the past year.

For those not familiar, CSA has been active in the development of wind energy conversion standards for a number of years. The work is directed by the Technical Committee on Wind Energy Conversion Systems of which Malcolm Lodge is the Chairman.

As I understand it, when the activity started some four years ago, the Technical Committee identified four areas that required standards. These were:

- safety
- performance
- electrical interface
- siting

As it stands at the moment, the Committee has produced standards to address all areas with the exception of the fourth item on "siting" which is nearing completion.

I will describe the status of the standards produced in a minute but before doing so I wanted to point out that the development of these standards is done largely on a volunteer basis. The participants in the CSA Committee activity which include many of the conference attendees have shown by the good progress made on the standards that they are dedicated to the task of developing these standards for the industry. Without these volunteers who give of their time and talent to draft the standards, the documents could not be produced. Due credit should therefore be given to the committee members and the members of the various S/Cs involved with the development of the standards.

The committee and its subcommittees have all been very active during the past year. The committee met the day after your conference last year and followed up with a meeting in June. Two of the subcommittees have also had meetings. The performance subcommittee met in June and the safety subcommittee met three weeks ago in Toronto.

One item which caused some concern to CSA and others was the transfer of the energy program from NRC to EM&R as the standards program was formerly funded under the NRC program. In my opinion this concern was really unfounded as the transition went very smoothly. The standards work proceeded without any holdup and the cooperation from EM&R staff has been excellent.

Turning to the standards themselves two new documents were published during the past year. This now brings the count to three. All three are referred to as preliminary standards. A decision was made early on in the work of the committee to issue the standards as preliminary standards so that they could be produced in a relatively short time. The reason for doing this was to try to get the documents into the field so that feedback could be obtained and improvements made to the documents. This has worked very well and was a wise move by those who recommended this approach.

I will now give you a brief status report on the three standards that have been produced.

F416 - This is the safety standard that was produced in 1985. Comments have been received on the standard and these will be taken into consideration in the development of the formal standard. The S/C responsible for the standard which is chaired by Raj Rangi of NRC is now working on the new edition. The main committee also asked the S/C to consider expanding the scope of the standard to apply to turbines larger than 100KW. Work is well underway on the preparation of the new edition and a S/C meeting is scheduled for early November.

F417 - This is the performance standard which was published in March after considerable work. The principal activity during the past year was the program that was initiated to verify the standard. The electrical generation and battery - charging provisions were reviewed by the Atlantic Wind Test Site. The water pumping provisions were reviewed by Dave Baker at the Lethbridge Alberta test site. This verification work has been completed. The S/C involved which is chaired by Ray Richards has also deliberated the results of the work. In the coming months the S/C will determine what changes it would like to see made to the standard to reflect the information and experience gained from the verification program. I understand that later during the session Dave Baker and Carl Brothers in their presentation will elaborate on the programs they carried out and the results they obtained.

F418 - This is the standard that covers interconnection of WECS to the utility. The preliminary standard was published in February last year. No activity has taken place in the meantime however, it is expected that work will begin in the coming months to convert this standard to formal status. The chairman of the S/C responsible is Jim Lea.

I mentioned earlier that the technical committee had identified the need for a standard on siting. A draft standard (F428) has been prepared and is nearing completion. It will give guidance on the evaluation of a site proposed for wind energy utilization. It is hoped that this standard can be finished up to compliment the other three documents.

CSA has been making efforts to publicize the availability of the wind energy standards that have been published. We produced a brochure recently which we distributed to a mailing list of approximately 2000. We hope that by making these efforts now and in the future that it will help publicize the availability of these standards and increase the sales of the documents.

Before finishing my report I just wanted to mention that tomorrow the TC will meet here in the hotel. One major item on the agenda will be to firm up plans to establish a S/C on installation. It is felt that an installation standard is required and the necessary plans will be put in place to develop such a document. I wanted to also point out that the safety subcommittee has scheduled a meeting for November 5th at which time it will proceed with the work I described earlier.

In closing I want to take this opportunity to thank Malcolm Lodge and the other committee members for their cooperation during the CSA staff transition from Bill Porter to myself.

EVALUATION OF CSA PERFORMANCE STANDARDS
- Test Site Perspective -

Carl Brothers - Atlantic Wind Test Site
Dave Baker - Lethbridge Water Pumper Test Facility

INTRODUCTION

The Canadian Standards Association with the support of the National Research Council began several years ago to develop a series of standards to ensure the safe use of wind energy conversion systems (WECS). These standards, which will serve as guidelines for the safe design, installation and operation of WECS, have been developed by CSA in conjunction with various government and private organizations.

The CSA standards were developed in parallel with similar standards by the American Wind Energy Association (AWEA) and by the International Energy Agency (IEA). These standards are similar in structure and content to the CSA standards but each of the standards are unique in several categories. The CSA Performance Testing Standard is unique in its control of Minimum Data Base Requirements (MDBR), air density corrections, and testing of battery charging, grid-connected and water pumping systems.

With the release of the preliminary CSA Performance Standard, it was agreed that the standard would be tested by an appropriate test site to determine the practicability of the standard. The Atlantic Wind Test Site (AWTS) was chosen to perform the sections related to grid-connected WECS and battery charging units while the water pumpers were to be tested by the Lethbridge Water Pumping Test Site (LWPTS). The tests were to be carried out in accordance with the standard and a report issued on the results describing any concerns related to the standard that were raised by the tests. Tests were commenced in late 1985 and completed in March, 1986. The following paper summarizes the results of these studies.

CSA PERFORMANCE STANDARD

The CSA Performance Standard was developed to provide a method of objectively evaluating a wind turbine's performance (power output over a range of windspeeds) in an actual field installation over a period of time. The standard describes in detail the tasks necessary to perform the test. It specifies the site requirements, the installation method of the machine to be tested, and the placement and accuracy of the instrumentation necessary to monitor the machine. The data collection and correlation methods, as well as the data averaging and minimum data base criteria, are all well described. With the accumulation of adequate data, the power curve and the estimate of annual energy output based on various average windspeeds is then computed. These requirements are very similar to the IEA and AWEA standards.

The CSA method of determining the minimum data base requirement is unique in WECS testing standards. Both the AWEA and IEA standards require an arbitrary number of output power and windspeed samples for each "bin" (a bin represents a small range of windspeed, i.e. 0.5 m/sec bins would mean there are 40 bins between 0-20 m/sec), and tests are not complete until the required number of samples for each bin is completed. The CSA standard attempts to reduce the amount of time required to complete the test as well as provide an indication of the precision of the data by applying a statistical test to the data within each bin.

Basically all values within a particular windspeed bin vary around the mean of the value within that bin. Statistically the confidence in these values is increased if the values are very close to the mean of the bin. On the other hand, if the values are scattered less confidence is obtained. It follows then that the same confidence might be obtained by a smaller number of values close to the mean as with a larger number of more scattered values. The CSA standard determines whether and when a smaller number of values can validate a bin using the student 't' test. This validation controls the data such that there is a probability of 0.99 that the true mean is within 5 to 10% (depending on the level of wind speed) of the sample's mean.

The CSA Performance Standard on battery charging and water pumping are also unique to CSA in WECS standards. In the CSA standard the WECS are tested in a manner consistent with actual field operation and the performance test is intended to test a complete installation. Other standards assume that these types of WECS can be accurately tested by following the same procedures used in testing grid-connected units.

TEST SEQUENCE

The test unit for grid-connected WECS was an Indal 9m X 6m, 7.5 kW VAWT located at the AWTS. The battery charging unit used was a Bergey BWC 1000 also located at the AWTS. A complete description of the test on these units can be found in Reference 2.

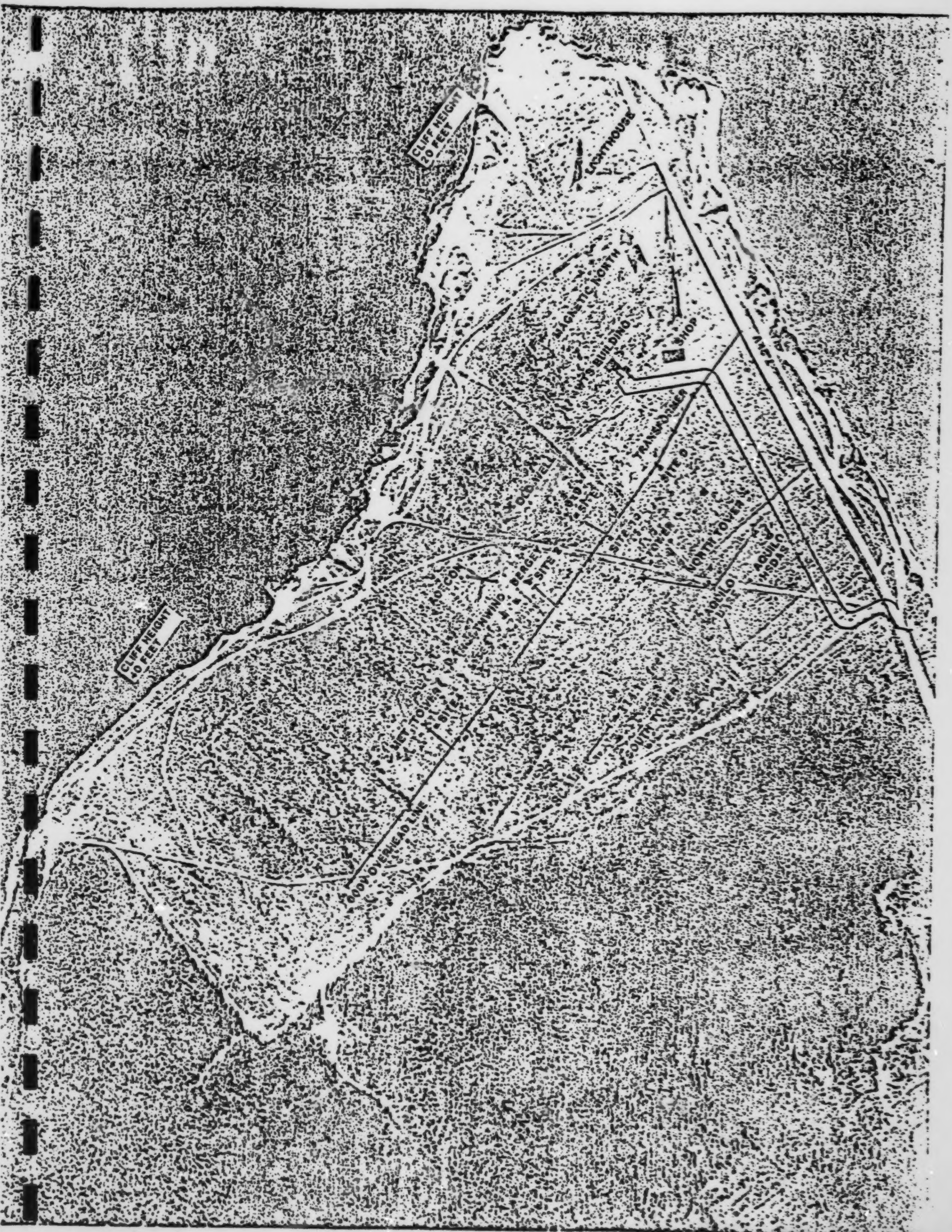
The test of the water pumping section of the standard was conducted by DRB Engineering Consultants on behalf of the LWPTS on a Bowjon airlift wind turbine. This test is described in detail in Reference 3.

TEST RESULTS

The tests on the two units at the AWTS concluded that the standard was quite practicable although some specific concerns were raised.

The power curve obtained from the 9x6 VAWT was as expected. The only concern arising from the test was the difficulty that the unit had in meeting the CSA minimum data base requirements on a consistent basis and whether this difficulty stemmed from the standard, the machine or the topography (Figure 1).

The Bergey battery charging unit raised several interesting points. It too had problems meeting the minimum data base requirements. Other problems related to validity of data were also noticed. All instrumen-


CLIFF HEIGHT 20 FEET
LIGHTHOUSE
MAGNETIC NORTH
WTS BUILDING
SHOP
TRANSFORMER
SITE D
SITE C
SITE B
BERGE
NORTH TOWER
AQUILO
SITE A
SOUTH TOWER
CLIFF HEIGHT 40 FEET
6000 OVERHEAD LINE

tation was calibrated and the test results monitored daily, yet in the final data base, points obviously not valid were present (Figure 2). Some of this can be attributed to an intermittent problem in a new anemometer wire, others to icing, but the presence of questionable data values points out the necessity of detecting and eliminating the bad data. Another finding of the battery charging test was a discrepancy between the field test and a mathematical model developed by, among others, members of the performance subcommittee. The model predicts a power curve that varies significantly with the battery terminal voltage as outlined in Reference 4. Test results do not show this (Figure 3 and 4). In fact estimates of the annual energy output for the wind turbine at various voltage levels did not vary at all with varying voltage levels. Whether this is due to simplifying assumptions on the part of the model or dynamic effects of the wind turbine/controller or some other unexplained reason is not clear.

Other points of concern raised during the AWTS test were related to anemometer spacing on a separate unit under test. Aquilo, an Indal 500 kW VAWT, had been under test at AWTS for some time with anemometers installed to the north and to the south of the machine as recommended in the standard. When power curves were developed based on data collected from each anemometer significant differences were found. Subsequent testing suggests a flow anomaly at AWTS that may be responsible for this difference but this potential terrain effect has implications for any standards test.

The test of the water pumping WECS at the LWPTS monitored the performance of the Bowjon airlift pump over a three month period. The findings from this test indicate again that despite the standard being quite workable the data base requirements were difficult to meet particularly near cut in and cut out windspeeds (Table 1).

CSA MODIFICATIONS

Subsequent to the submission of the two reports on standards evaluation, the CSA subcommittee proposed some alterations to the standard and recommended some further work as suggested by the test reports.

The difficulty in meeting the minimum data base requirements was due in part to the equation which determines minimum standard deviation:

$$\sigma < \frac{0.05p\sqrt{n}}{t}$$

where σ = standard deviation
p = average power
n = number of data points
t = 't' statistic

At low power levels the standard deviation must be extremely low to meet the specification. For water pumpers this problem was further exaggerated by the hysteresis of operation near cut-in. This hysteresis

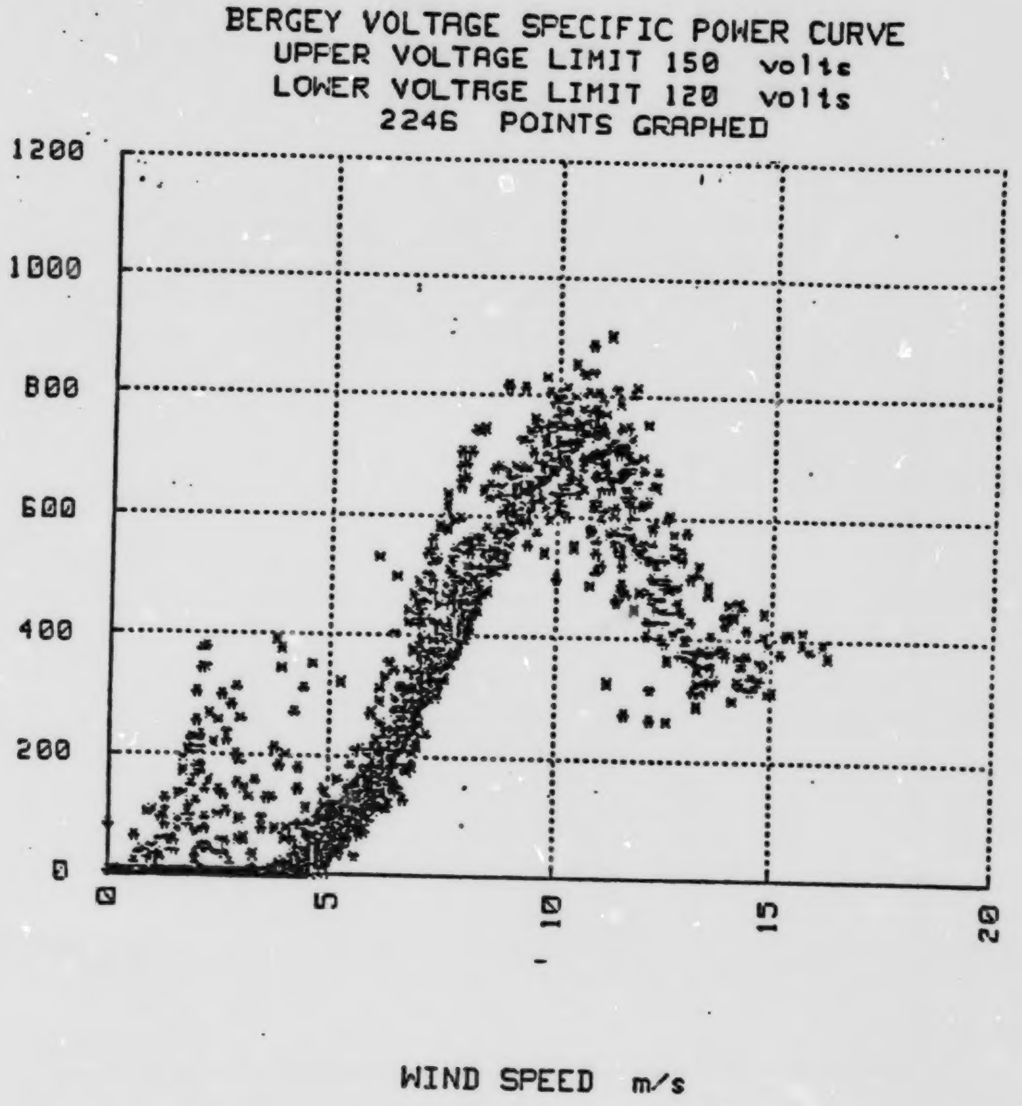

BERGEY VOLTAGE SPECIFIC POWER CURVE
UPFER VOLTAGE LIMIT 150 volts
LOWER VOLTAGE LIMIT 120 volts
2246 POINTS GRAPHED
POWER Watts
1200
1000
800
600
400
200
0
0
5
10
15
20
WIND SPEED m/s

Figure 2

```
Selected degree of regression =  5

                                        95 % CONFIDENCE INTERVAL
                   COEFFICIENT        LOWER LIMIT        UPPER LIMIT
'CONSTANT'          -52.34982          -71.59456          -33.10509
X^1                 228.11151          205.30814          250.91488
X^2                -137.69215         -146.67067         -128.71364
X^3                  29.61737           28.13111           31.10364
X^4                  -2.37002           -2.47800           -2.26204
X^5                    .06312             .06028             .06596
```

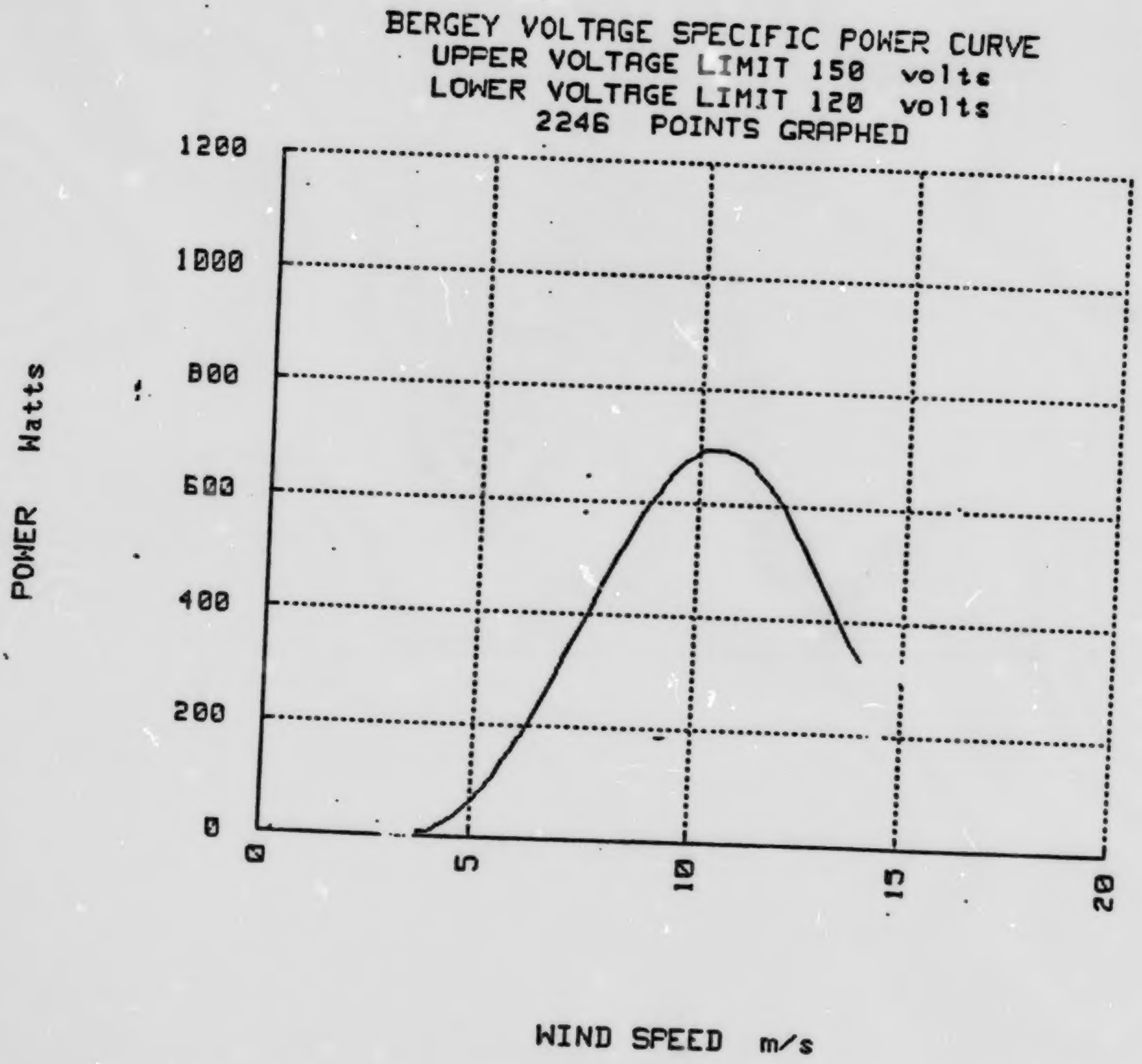


Figure 3

```
Selected degree of regression =  5

                                            95 % CONFIDENCE INTERVAL
                    COEFFICIENT          LOWER LIMIT        UPPER LIMIT
'CONSTANT'            -30.54240            -46.56716          -14.51764
X^1                    91.80926             64.43898          119.17954
X^2                   -62.49565            -77.29514          -47.69617
X^3                    14.72087             11.39265           18.04909
X^4                    -1.13747             -1.46187            -.81306
X^5                      .02695               .01570             .03820
```

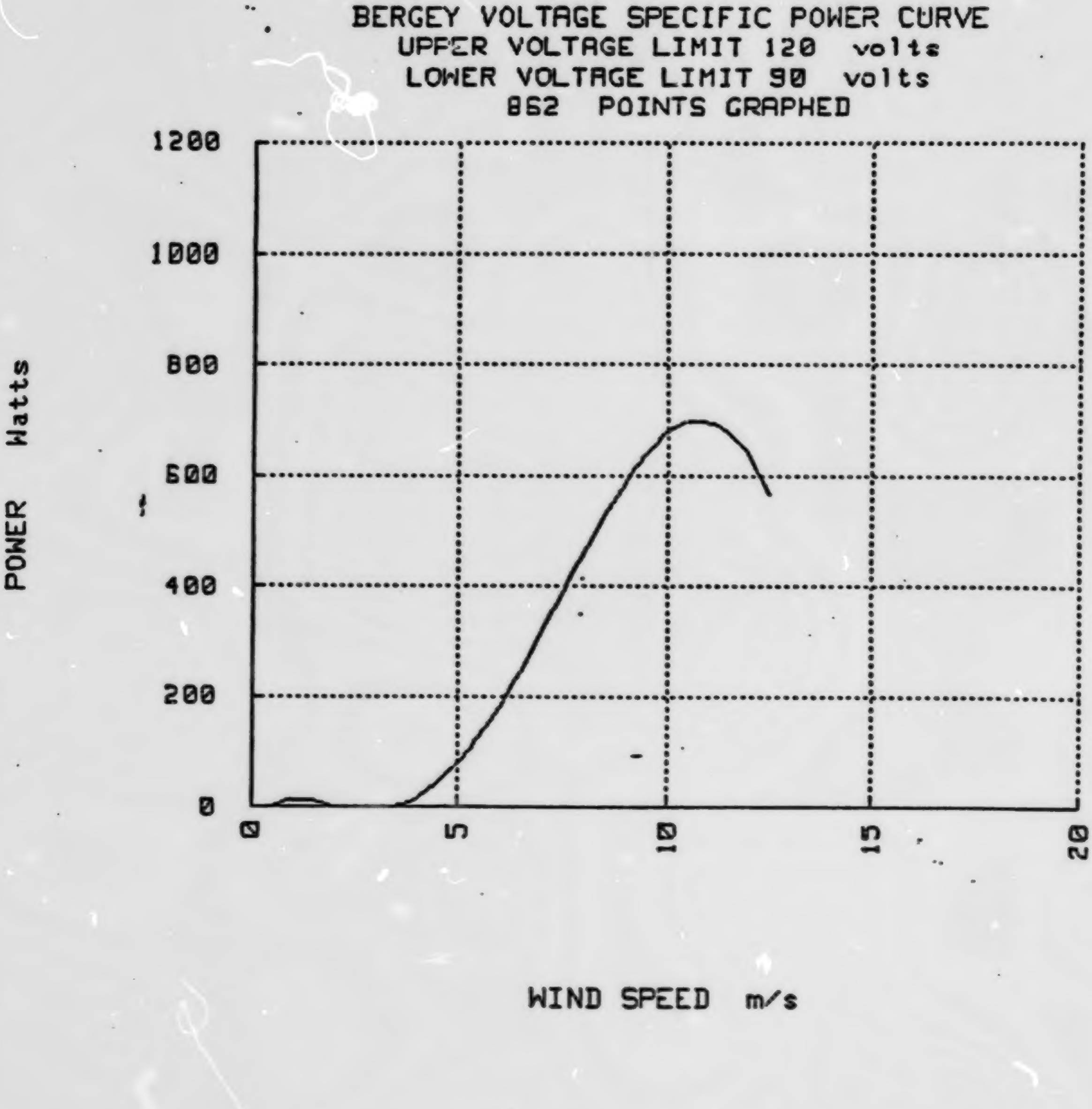


Figure 4

TABLE 1. ANALYSIS RESULTS

BIN NUMBER	WIND SPEED INTERVAL (M/S)	# OF DATA SETS	AIR DENSITY (KG/M3)	WIND SPEED (M/S) AVG	WIND SPEED (M/S) STD DEV	FLOW RATE (L/S) AVG	FLOW RATE (L/S) STD DEV	"T" VALUE	MAX FLOW STD DEV	FILLED? 1=YES
1	2.25 - 2.75	59	1.079	2.53	0.140	0.098	0.042	2.664	0.014	0
2	2.75 - 3.25	208	1.085	3.06	0.129	0.128	0.074	2.618	0.035	0
3	3.25 - 3.75	549	1.091	3.52	0.144	0.206	0.108	2.618	0.092	0
4	3.75 - 4.25	645	1.090	3.99	0.137	0.336	0.122	2.618	0.163	1
5	4.25 - 4.75	456	1.089	4.49	0.141	0.474	0.097	2.618	0.194	1
6	4.75 - 5.25	331	1.090	5.00	0.147	0.574	0.074	2.618	0.199	1
7	5.25 - 5.75	303	1.084	5.48	0.144	0.635	0.075	2.618	0.211	1
8	5.75 - 6.25	252	1.079	6.00	0.149	0.694	0.065	2.618	0.210	1
9	6.25 - 6.75	273	1.078	6.52	0.146	0.744	0.057	2.618	0.235	1
10	6.75 - 7.25	273	1.079	7.00	0.144	0.758	0.059	2.618	0.239	1
11	7.25 - 7.75	212	1.080	7.50	0.150	0.785	0.060	2.618	0.218	1
12	7.75 - 8.25	194	1.075	8.00	0.143	0.798	0.066	2.618	0.212	1
13	8.25 - 8.75	131	1.075	8.49	0.128	0.822	0.066	2.618	0.180	1
14	8.75 - 9.25	126	1.075	8.97	0.136	0.839	0.061	2.618	0.180	1
15	9.25 - 9.75	109	1.077	9.48	0.151	0.846	0.065	2.626	0.168	1
16	9.75 - 10.25	84	1.078	10.00	0.146	0.860	0.067	2.644	0.149	1
17	10.25 - 10.75	83	1.075	10.50	0.136	0.854	0.066	2.645	0.147	1
18	10.75 - 11.25	34	1.078	10.96	0.150	0.845	0.066	2.737	0.090	1
19	11.25 - 11.75	36	1.082	11.48	0.152	0.798	0.070	2.728	0.088	1
20	11.75 - 12.25	38	1.086	11.98	0.150	0.802	0.065	2.718	0.091	1
21	12.25 - 12.75	36	1.090	12.53	0.143	0.682	0.108	2.728	0.075	0
22	12.75 - 13.25	28	1.084	12.96	0.134	0.606	0.098	2.771	0.058	0
23	13.25 - 13.75	16	1.071	13.47	0.140	0.516	0.102	2.947	0.035	0
24	13.75 - 14.25	13	1.072	14.03	0.125	0.407	0.065	3.055	0.024	0
25	14.25 - 14.75	6	1.099	14.52	0.147	0.308	0.051	4.032	0.009	0
26	14.75 - 15.25	3	1.068	14.90	0.100	0.257	0.040	9.925	0.004	0
27	15.25 - 15.75	4	1.047	15.38	0.096	0.235	0.064	5.841	0.008	0

is caused by the fact that it takes more energy to overcome the static friction found in a stationary water pumper than to maintain the operation of a water pumper in motion (kinetic friction). At high power levels, which because of the wind frequency distribution seldom occur, you require an unrealistically large number of samples.

The minimum data base requirements have since been altered to compensate for the problems of low and high output conditions. This correction involved the adoption of the minimum sample criteria found in the IEA Standard for power levels below 25% of the WECS maximum output and for wind speeds above 15 m/s.

The subcommittee also recommended that:

1. Further work be done on the computer simulation model for battery charging WECS to better understand the discrepancy between model projection and field measurements.

2. Consideration be given to Chauvinet's criteria for spurious data removal as suggested in LWPTS water pumper report (Reference 3).

3. Wind tunnel studies of AWTS be done to resolve flow anomalies.

FUTURE REQUIREMENTS

The CSA standard, and others like it, go a long way in the establishment of procedures and standards in testing wind turbines. It must be recognized, however, that many issues affecting the testing of wind turbines are not yet well understood or documented. Because they are not fully understood they can potentially be sources of inaccuracies in wind turbine tests. These must be addressed and varying amounts of effort will be required to resolve the various issues.

Some issues to consider are:

Bad Data - Inevitably during a period of test some data will be bad. Whether this is due to weather conditions (ice, rain), data system or other problems it must be detected and deleted in a fair manner.

Weather Effects - How does rain affect turbine performance? How can we fairly account for temperature and pressure variations in turbine performance?

Terrain Effects - It is obvious that rather small terrain variations can cause substantial flow anomalies. The standard should provide rigid enough restrictions on locations of test sites to avoid this problem.

Machine Effects - Variable speed, dual speed or double generators can introduce some interesting effects on power curves depending on the dynamics of the machine or whether windspeed is increasing or decreasing. The testing of these types of machines may not be suitably defined in the standard.

Hysterisis - This is particularly significant in water pumpers but affects all wind turbines at cut in and cut out windspeeds. Should the test procedures be altered to yield both curves in the hysteresis cycle?

Turbulence Effect - The effect of varying amounts of turbulence on the power output of wind turbines is not well understood, but it is clear that it has significant dynamic effects on wind turbines and anemometers. Are changes in the standard required to reflect these effects?

CONCLUSIONS

Progress in standards development has been impressive. Now with the distribution of the preliminary standard, there may be some expectation that the job is done and it is now time for other things. However, an objective evaluation will reveal the job is not done; there are simply too many unanswered questions.

These questions cannot all be solved in the short term. Many may never be fully resolved, but we must all recognize that the development of standards is an ongoing activity, especially in so young an industry as wind energy. With the distribution of this standard, it is now up to the wind industry to put it to the test such that the standard can be quickly developed into an even more workable and accurate document.

REFERENCES

1. Canadian Standards Association Standard F417 - Wind Energy Conversion Systems (WECS) - Performance 1985.

2. Field Test of Canadian Standards Association Wind Energy Conversion Systems Performance Standard F417, Atlantic Wind Test Site, 1986.

3. Evaluation of the Canadian Standards Association F417 Standard Wind Energy Conversion Systems (WECS) - Performance as applied to Water Pumping Wind Turbines, DRB Engineering Consultants Ltd., 1986.

4. Accuracy of Power Curve Measurements, edited by C.J. Christenson (RISO) and J.B. Dragt (ECN), Draft 1986. Prepared under the auspices of the IMTSS and supported by the EEC, DGXVII.

WIND POWER IN ALBERTA

TWENTY-ONE MONTHS AFTER THE DECISION

A PRESENTATION TO THE CANADIAN WIND ENERGY CONFERENCE '86

OCTOBER 28, 1986

H. D. MILLER - TRANSALTA UTILITIES

WIND POWER IN ALBERTA

TWENTY-ONE MONTHS AFTER THE DECISION

A PRESENTATION TO THE CANADIAN WIND ENERGY CONFERENCE '86

OCTOBER 28, 1986

H. D. MILLER - TRANSALTA UTILITIES

On June 8, 1984, the Alberta Energy Resources Conservation Board (AERCB) issued its Decision D 84-12 regarding a wind-powered electric generator near Pincher Creek. In part of that Decision, the AERCB requested TransAlta Utilities collect information on the Small Power Producer (SPP) wind generators interconnected with its electric system. Specifically, TransAlta was to collect information, assisted by SPPs on the system, on the operation of the SPP facilities, and on their interaction with TransAlta's electric system and with the Alberta Interconnected System (AIS).

This paper will provide a detailed account of the results of the data collection during the first twenty-one months of operation from January 1985 to September 1986.

Monitoring equipment was installed at three SPP sites: one near Cardston, at 5 KW; two near Pincher Creek, at 5 KW and 40 KW.

Figure 1 shows that during the 21 month period, the three SPPs generated a gross total of 203,354 kilowatt hours (kWh) of electric energy. When energy generated by an SPP exceeded its immediate needs, the excess energy was "banked" in TransAlta's electric system. Then, during times of low or no winds, this banked energy could be withdrawn from the electric system to meet the SPP's needs. Through this "quarterly net energy banking", one of the SPPs generated enough energy to fully meet its own energy use. The other two SPPs purchased some energy from TransAlta to supplement their wind generators' output. The total amount of energy used by all three SPPs, whether supplied by the wind generators or purchased from TransAlta, was 170,585 kWh.

Of the 203,354 kWh of gross generation, net generation (in excess of immediate needs) of 133,556 kWh was banked in TransAlta's electric system for later use or sale to TransAlta.

During operation, the wind generators required 106,925 kilovolt ampere hours of reactive energy (kVArh).

Based on gross generation, the three wind generators operated at an average capacity factor of 26.6% as shown in Figure 2. Capacity factor is the ratio of actual energy generated in a period to the potential energy that could have been generated had the facility operated at its rated capacity over the entire period. This number compares favourably with other wind generators operating in California as indicated in Figure 3.

Figure 4 indicates the various availability factors. The average resource availability was 48.6% over the year. This is the percentage of the time that wind conditions were suitable for wind generator operation. Average TransAlta equipment availability at the SPP sites was 99.9%. Average SPP equipment availability was 84.7%. These three availabilities combine to give an overall availability factor of 41.2%.

An analysis of TransAlta's peaks in 1985 revealed that the monitored wind generators contributed to four of the twenty highest demands (Figure 5).

The power duration curves in Figure 6 shows a representation of the SPP's generated power as a percentage of time for all hours and peak hours.

The accompanying tables and figures provide some of the detailed data collected in the 21 month period.

TABLE 1

SMALL POWER PRODUCTION SUMMARY, KILOWATT HOURS AND KILOVAR HOURS

	Cardston 5 kW Enertech Wind Generator	Pincher Creek 5 kW Enertech Wind Generator	Pincher Creek 40 kW Enertech Wind Generator	All Three SPPs 50 kW Combined Generating Capacity
Gross Generation from SPP (kWh):	12,297	18,243	172,814	203,354
Energy Used (kWh):	50,643	20,130	99,812	107,585
Net Generation from SPP (kWh):	1,370	11,107	121,079	133,556
Reactive Energy Required (kVArh):	6,170	14,031	86,724	106,925

TABLE 2

SMALL POWER PRODUCTION CAPACITY FACTORS

	Cardston 5 kW Enertech Wind Generator	Pincher Creek 5 kW Enertech Wind Generator	Pincher Creek 40 kW Enertech Wind Generator	All Three SPPs 50 kW Combined Generating Capacity
Gross Generation (kWh):	12,297	18,243	172,814	203,354
Period Hours (hrs):	15,308	15,210	15,287	45,805
Potential Generation (kWh):	76,541	76,049	611,470	764,060
Capacity Factor (%)	16.1%	24.0%	28.3%	26.6%

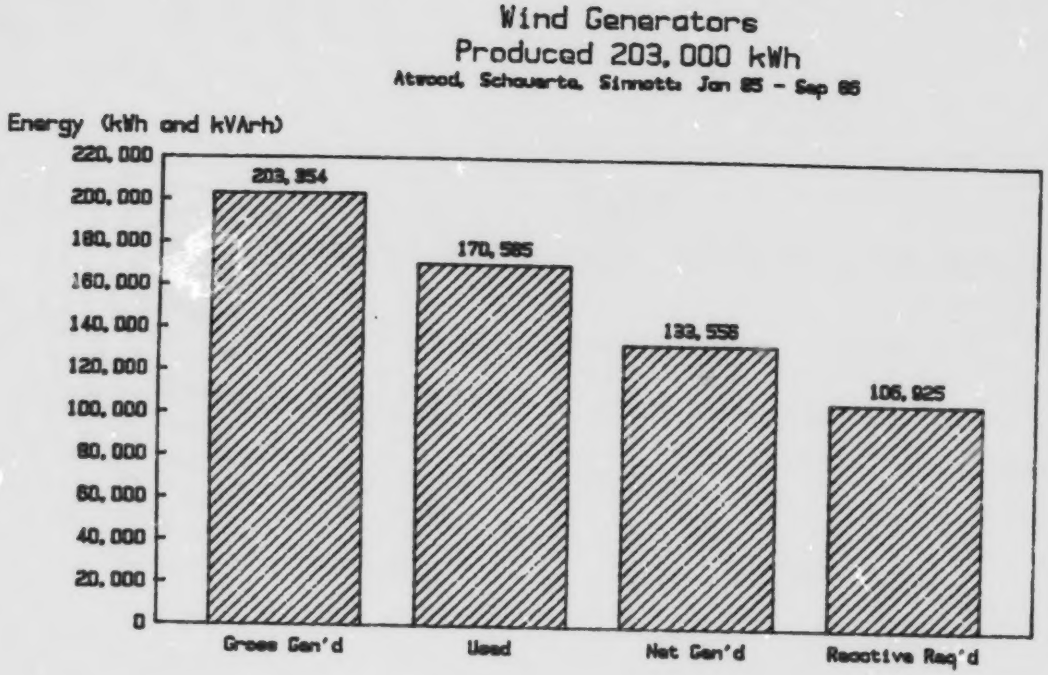

Wind Generators
Produced 203,000 kWh
Atwood, Schouerta, Sinnott: Jan 85 - Sep 86

Figure 1

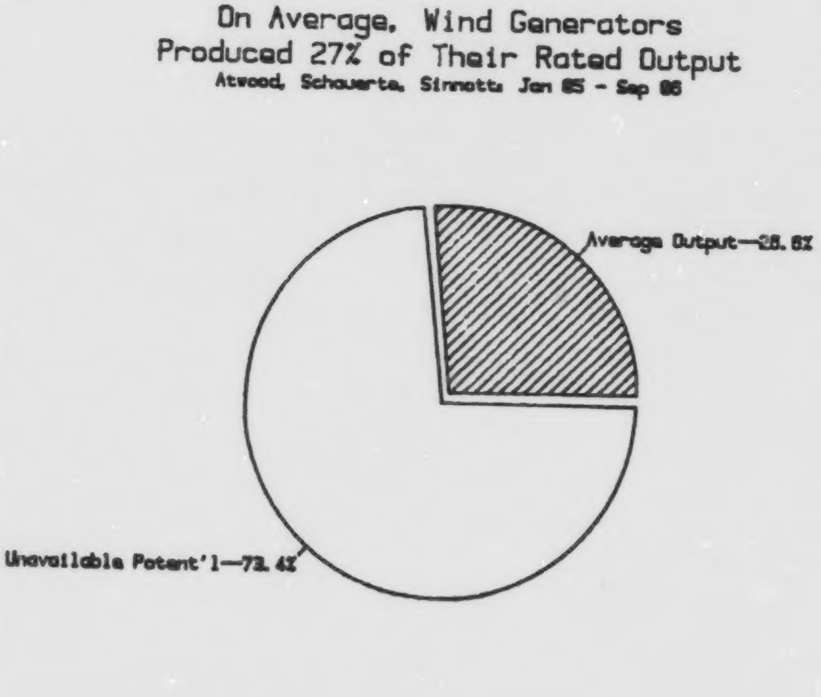
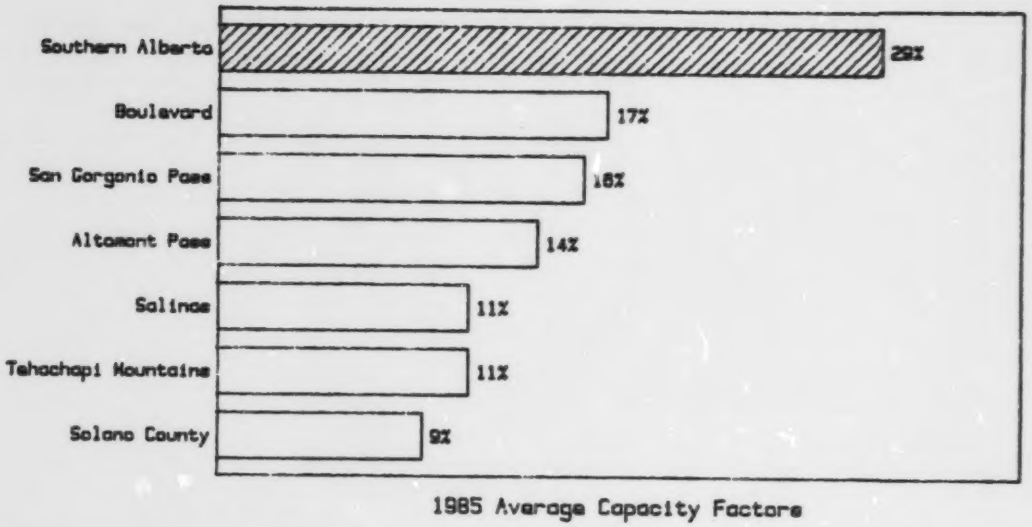

On Average, Wind Generators
Produced 27% of Their Rated Output
Atwood, Schouerta, Sinnott: Jan 85 - Sep 86

Figure 2

Wind Generators in Southern Alberta Performed Better Than Wind Generators in California
1985



1985 Average Capacity Factors

Based on "Analyzing 1985 Wind Project Performance" in the August/September 1986 issue of Alternative Sources of Energy magazine.

Figure 3

Overall Availability Was 41%
Atwood, Schouerte, Sinnott: Jan 85 - Sep 86

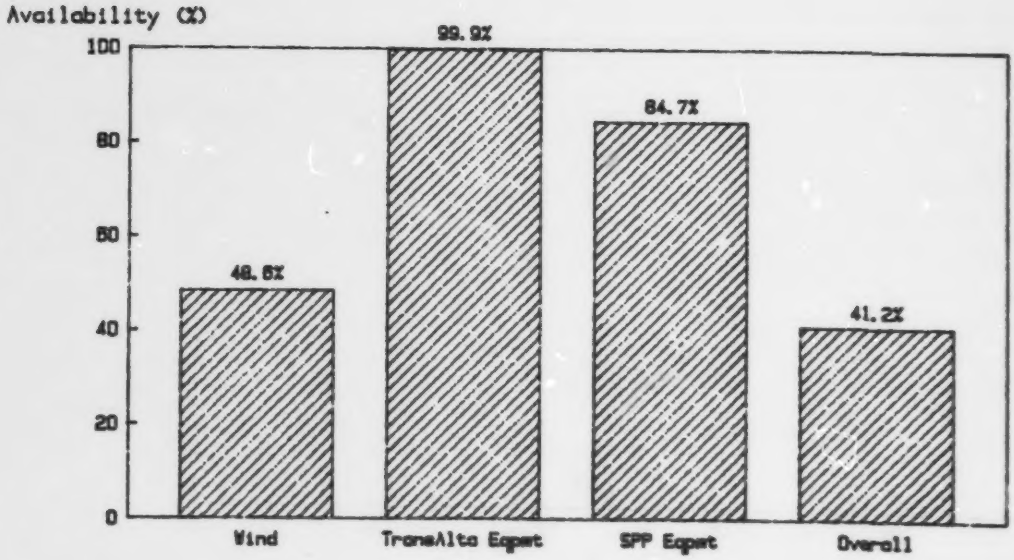


Figure 4

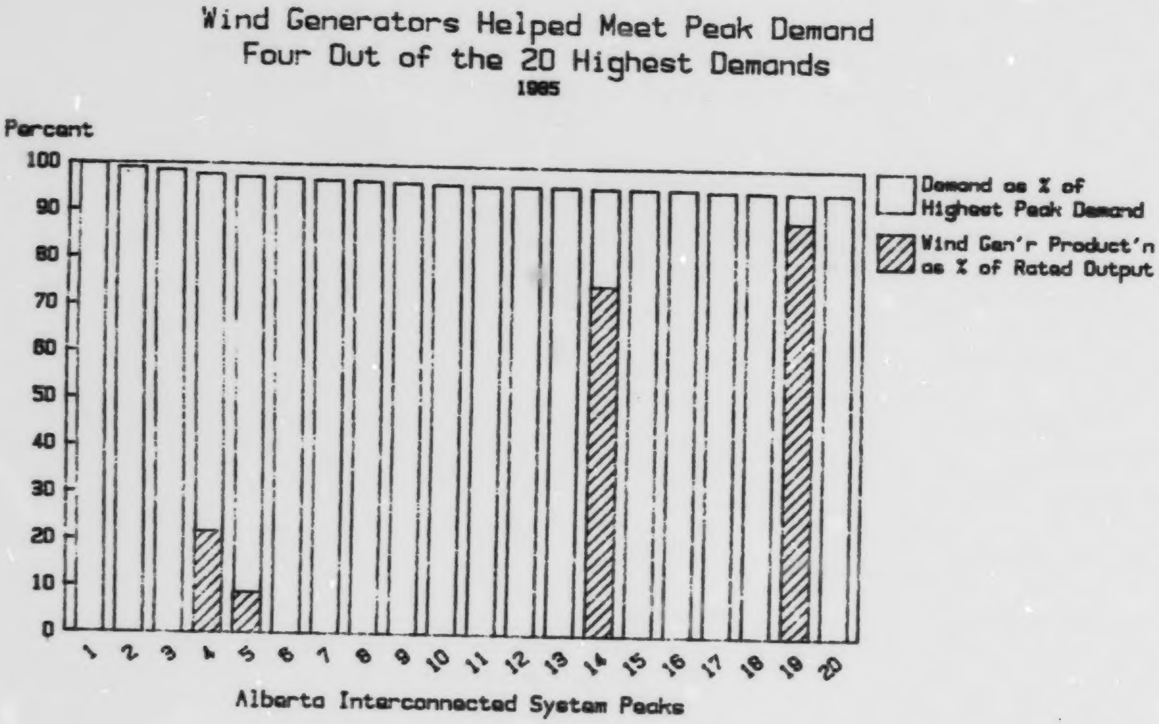
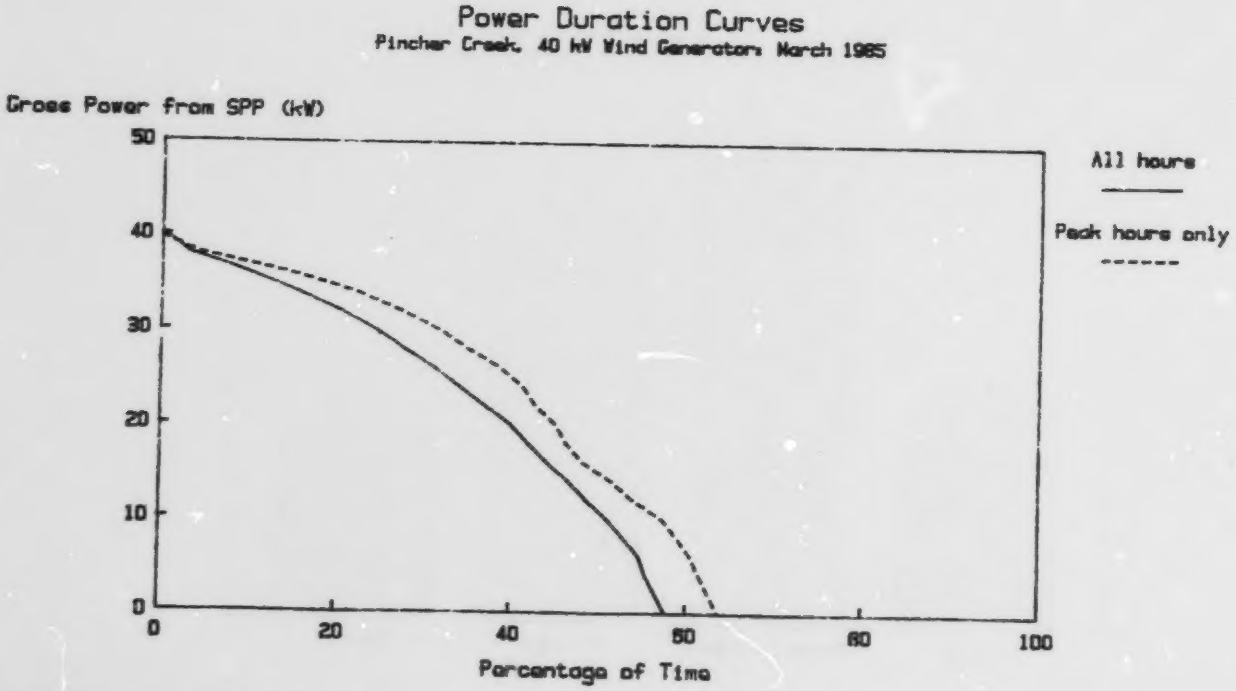


Figure 5



"Peak hours" are from 9:00 am to 9:00 pm on non-holiday weekdays.

Figure 6

There are three major issues involving TransAlta Utilities and the SPPs in Alberta today. The first is the change to an annual banking concept. This means the wind power generator will be able to bank energy during the winter months (October to March), and draw on that banked energy during the following six months (April to September). During that period SPPs can also draw during the winter months when required and any banked energy in the first six month period can then be drawn on during the following six month period.

A second issue that has yet to be resolved is remote site generation. It is now being discussed whether remote site generation of some sort should be instituted where the generator will be installed at a particular site and permitted to transfer generated energy to a load at a designated service, at a predetermined distance. Remote site generation presents some problems in that a service needs to be supplied to the wind generator at which there is no load or revenue for the electric utility. The distribution lines over which this energy is moving then enters the cost equation and the question of whether or not there should be a factor put into that whole purchase power equation for that purpose.

The third issue is multiple service banking which concerns the wind generator's output being permitted to bank against more than one service. In a number of places in Southern Alberta there are large farms that have, for example, a number of irrigation services under one particular name. If this particular issue was resolved to the point that multiple service banking would be permitted, then a wind generator could be installed at its best available site and banked against the summation of a number of services. Some of the concerns associated with this arrangement are:

1. Costs of transmitting this energy over long distances;
2. What factors determine the maximum distance between the generator and the loads to be served.

Some suggestions have been a 15 kilometre radius from the wind generator, or the loads being banked against must be on contiguous land that is owned or leased by the particular owner of the wind generator.

These are issues that will be discussed in the very near future with the Small Power Producers Association of Alberta in conjunction with the Alberta Energy Resources Conservation Board and the Public Utilities Board.

Conclusion

Long range planning in Alberta indicates that the most economical method for supplying the electrical needs of Alberta lies with coal fire thermal generation. We do realize there are advantages to smaller incremental units, however, the economics must be attractive. TransAlta will continue to work with the small power producers as well as monitor the contribution these units can make to the power requirements of Alberta. The primary concern must be in all cases, safe and reliable electric energy at the lowest possible cost to consumers.

GOVERNMENT AND INTERNATIONAL AFFAIRS

THE CANADIAN WIND ENERGY R,D&D PROGRAM
(LE PROGRAMME CANADIEN DE R,D&D EN MATIÈRE)
D'ÉNERGIE ÉOLIENNE

M. Carpentier, P. Eng
Technology Co-ordinator
Renewable Energy Branch
Energy, Mines and Resources Canada

PROGRAMME DE RECHERCHE ET DE DÉVELOPPEMENT

Suite à la rencontre qui a eu lieu à Montebello, Énergie, Mines et Ressources a établi un programme de Recherche et de Développement en énergie éolienne qui regroupe 6 secteurs d'intérêt:

- La recherche de base
- Le développement technologique
- Le développement de systèmes hybrides éolienne/diesel
- L'évaluation et le monitoring des équipements
- Les parcs d'éoliennes, et
- Le transfer de la technologie

Le budget total couvrant tous ces secteurs était originalement 750 000 $ auquel venait s'ajouter le support financier du Conseil National de la Recherche pour le site de l'Île-du-Prince-Édouard (AWTS).

En décembre 1985, Énergie, Mines et Ressources publie sa première demande de propositions. Tous groupes intéressés pouvaient alors soumettre une ou plusieurs propositions. La réponse du public a été très intéressante et a même surpassée nos attendes. Nous avons reçu, pour des travaux de recherche ou de développement en énergie éolienne, 51 propositions pour un coût total de 10 millions de dollars.

Ces propositions ont été évaluées par un groupe composé de 4 à 5 personnes selon le domaine d'intérêt afin de sélectionner les meilleures propositions au niveau technique et celles qui se conformaient le plus à nos priorités.

Vingt-deux contrats ont été adjugées pour l'année financière en cours. Ces contrats se répartissent comme suit:

	Nombre de contrats	EMR Contribution
Recherche de base	3	104.7K
Développement technologique	4	210.0K
Développement de systèmes hybrides	4	266.0K
Évaluation et monitoring des équipements	8	276.9+200K
Les parcs d'éoliennes	1	18.9K
Transfert de l'information	2	15.0K
Total	22 contrats	1091.5K

En recherche de base, nous avons subventionné des travaux d'étude sur le comportement des éoliennes lorsqu'il y a accumulation de glace; sur le développement de modèles de simulation pour des éoliennes Darrieus incorporant des attaches de pales à charnières; et sur l'étude de nouveaux concepts de fondation pour des éoliennes devant être installées dans les régions éloignées.

Une part importante du budget a été alloué pour l'amélioration des équipements éoliens et leur évaluation en milieu réel. Il semble évident que le niveau de pénétration des éoliennes canadiennes sur le marché intérieur et d'exportation ne pourra se faire que si celles-ci se comparent favorablement avec les éoliennes étrangères en ce qui a trait aux facteurs fiabilité et rentabilité. Des projets tel que l'incorporation de pales à charnières sur l'éolienne d'ADECON, la modification, la reconstruction et l'évaluation de l'éolienne de Indal Technologie de même que l'évaluation de l'éolienne MBB-15, dont Thermax est le représentant canadien, figurent parmi ces contrats. Le support financier accordé aux terrains d'essais de l'Île-du-Prince-Édouard (AWTS) de même qu'au site de Lethbridge font également partie de cette catégorie.

Parmi les contrats au niveau du couplage éolienne/diesel, figure les contrats d'importance figurent l'établissement d'un banc d'essais, au AWTS. Ce banc d'essais lorsque complété sera mis à la disposition des groupes intéressés dans le domaine. L'Institut de Recherche d'Hydro-Québec (IREQ) fera également des travaux de recherches sur le couplage éolienne/diesel.

Comme je l'ai mentionné plus tôt, la contribution d'Énergie, Mines et Ressources à ces contrats est de 1 091 500 $ et le coût total des projets incluant la participation du secteur privé et de 1 562 400 $. Le pourcentage de contribution du gouvernement fédéral et donc de 70 %. La contribution d'EMR est également supérieure d'environ 150 000 $ au budget accordé par la R&D, comme annoncé dans la demande de propositions en décembre dernier.

Last year, the appropriation of funds by technologies was mainly based on historical allocations. This year, EMR has decided to issue a Request For Proposals with no specific funding allocations per technology. All proposals will be selected on the basis of technical quality, competence of the proposer and relevance to program objectives. This means that there will be no preset limit to the budget for wind in the next fiscal year. This also holds true for all other technologies. I am, however confident that the quality of your proposals will justify an increase in expenditures for wind energy projects.

In October, the Technical Advisory Committee held a meeting in Ottawa to review the contracts awarded and how they have progressed and to discuss the priorities for the coming fiscal year. These priorities have been broken down into four sectors as follows:

- Grid-connected WECS	(400K)
- Wind/Diesel Systems	(250K)
- Stand Alone Systems	(50K)
- Water Pumping	(50K)
	(750K)

The continued support to the two testing facilities was also recognized as a priority.

We will tie this year's activities to the potential market sectors and we will entertain proposals related to the different stages of development such as basic research, technology improvement or testing for each of these sectors according to the State-of-the-Art in each of these sectors. To represent the relative importance of the four sectors, the dollar figure will remain the same as last years' budget. However, as mentioned previously, these figures will be used as a guide only. No funding allocations between technologies prior to evaluating the proposals will be established.

The Department of Supply and Services will be announcing the Request for Proposals in the December 1986 issue of the R&D Bulletin. Only one closing date has been set - February 16, 1987 - to ensure a quicker turnaround time in the allocation of contracts.

Other importants events also happened during last year.

ATLANTIC WIND TEST SITE (AWTS)

The Atlantic Wind Test Site (AWTS) was established as a national testing facility in 1980. In order to ensure a proper site operation, the National Research Council (NRC) entered into a 10-year agreement with AWTS to offset operating losses of up to a maximum of $200,000 per year.

In July of 1986, the NRC assigned its rights and obligations under this agreement to EMR. EMR is now assuming responsibility for the funding and management of AWTS as part of its mandate in Wind Energy. This transfer also assured the availability of the $200,000/year for the remaining years of the agreement.

At several meetings, it was discussed to change the Directorship in order to better represente the users and manufacturers of Wind Energy Conversion Systems (WECS). We have asked both the Canadian Wind Energy Association (CanWEA) and the Canadian Electrical Association (CEA) to each select a representative to assume Directorship of AWTS.

From this change in Directorship, it is hoped that the services provided by the AWTS will be in accordance with the wishes of the wind energy community. It will also ensure that all the aspects of a successful wind energy development strategy will be incorporated into the AWTS activities from the research aspects, the manufacturing aspects as well as the users perceptions of WECS. I am very confident that the participation of the industry and utilities will be beneficial to the future activities of the Atlantic Wind Test Site.

This provides you with an overview of what has been done in R&D activities last year and also of what is planned for next year.

TAX INCENTIVES

Canada has very limited tax incentives in renewable energy compared to those found in some other countries. The February 1986 budget proposed to include wind energy equipment in the category of energy conservation equipment which qualifies for faster capital cost allowance write-offs. Equipment generating electrical energy from wind, for use in a business, is now eligible for a three year write off.

The tax concession represents a small vistory in the area of tax incentives for wind energy equipment considering that it occurred at a time when reducing the federal deficit was the main government priority.

No other tax incentive exists specifically for wind energy development. However, investment tax credits for the manufacturing sector, investment tax credits in respect of scientific research, and the Cape Breton investment tax credits are also available. These tax credits range from 7% to 60% depending on the type of project, its location and the status of the investor.

RELATED DEMONSTRATION PROGRAMS

The Renewable Energy Branch is also responsible of two demonstration programs of interest to the wind energy community: the Special Projects Demonstration and the Remote Community Demonstration Program.

Special Projects Demonstration

The objectives of this demonstration effort are to accelerate the adoption and commercialization of renewable energies as well as to increase the awareness by the Canadian public and the commercial sector, of the opportunities for their utilization. The Special Projects Demonstration is meant to be a link between research and development activities and product commercialization. Technology transfer is an important part of this demonstration as these types of projects produce valuable information in support of the renewable energy industry in terms of improved systems and cost performance.

Remote Community Demonstration Program

The Remote Community Demonstration Program which was introduced in 1982 is designed to encourage communities not connected to the main electrical grid or

natural gas supply system, to identify and implement viable energy conservation and alternative energy opportunities. Wind energy, primarily in conjunction with diesel power systems, is a Program priority.

Afin de vous donner une idée du genre de projets subventionnés, en voici une description.

Calvert Island Radio, Colombie-Britannique

Exploité par la British Columbia Telephone Co., Calvert Island Radio est un système analogique de micro-ondes qui dessert la côte nord de la Colombie-Britannique. L'île Calvert est située à 80 km au nord de Vancouver et est habitée uniquement par l'opérateur de la station de communication et sa famille. Un générateur diesel de 25 kW situé sur une colline de 170m fournit l'énergie au site radio par le biais de 1 km de ligne de transmission à haut voltage. L'île est accessible seulement par bateau ou hydravion. La charge totale varie entre 16 kW et 20 kW et le coût d'opération annuel est de plus de 140 000 $.

L'île Calvert est reconnue pour ses périodes ensoleillées durant l'été et ses forts vents de septembre à avril. Une combinaison de plusieurs sources énergétiques était donc prescrite pour minimiser les coûts d'opération.

Un nouveau système hybride y sera donc installé et il sera composé de:

- deux éolienne de 2000W (HR-2) produites par Northern Energy System
- un système photovoltaique de 1.2kW
- un générateur diesel de 10kW
- un groupe de batteries de 3 000 A/hr conçu pour suffir à la demande d'une période de 6 jours

Cette installation hybride permettra de réduire le facteur d'utilisation de la génératrice diesel à 10 %. Ce projet, d'un coût total d'environ 400 000 $ a une période de récupération de l'investissement de 3 ans. La contribution d'EMR pour ce projet était d'environ 130 000 $.

Deltx Windpump, Alberta

La compagnie Ducks Unlimited reconnue pour ses projets écologiques, fera installer dans le sud de l'Alberta la plus grande éolienne au monde conçue pour le pompage de l'eau. Cette éolienne de 20 m de diamètre construite par Deltx Windpump pompera de l'eau au taux de 1.5 x 10^6 m^3/année sur une hauteur de 10 m. L'eau ainsi pompée sera distribuée à l'aide d'un canal de 7 km de long et créera des marécages dans lesquels les canards et autres oiseaux migrateurs pourront se reproduire. Aucune source d'énergie électrique n'est disponible présentement sur le site. Le coût total du projet est d'environ 400 000 $ et la période de récupération de l'investissement est de l'ordre de 11 ans pour un coût d'énergie évaluée à 5¢/kWh. Une contribution de 131 000 $ sera versée par EMR.

Radio MF Charlevoix, Québec

Ce projet consiste à alimenter en électricité une station émettrice radio à l'aide d'un groupe électrogène assisté d'une éolienne. Le poste de radio communautaire CIHO-MF situé à Charlevoix au Québec n'est pas desservie par Hydro-Québec. La ligne de transmission la plus proche est à 3 km de distance. Pour des raisons de fiabilité, l'installation sera dotée, en plus d'une éolienne de 10 kW, d'une génératrice pouvant subvenir aux besoins électriques de l'émetteur pendant de longues périodes. Une petite génératrice d'urgence et un groupe de batteries de 100 kWh viendront compléter le système. Le coût total du projet est d'environ 170 000 $ et sera récupéré sur une période d'environ 15 ans. Ce projet est marginal au niveau financier due à la proximité du réseau électrique et à l'accès relativement facile au site. Ce projet servira surtout à démontrer le potentiel d'utilisation des éoliennes pour ce type d'application. EMR contribuera 92 000 $ à ce projet de démonstration.

Kuujjuaq (Fort Chimo), Nouveau-Québec

Ce projet, mis sur pied par Hydro-Québec, permettra de démontrer la faisabilité technique d'installer une éolienne sur un réseau électrique alimenté au diesel en vue d'économiser du pétrole dans les communautés éloignées. Une éolienne danoise de 65 kW produite par la compagnie "Bonus" a été installée en septembre dernier par Hydro-Québec et a été reliée au réseau diesel. Cette éolienne devrait produire environ 120 000 kWh par année à un coût d'environ 24¢/kWh, donc bien inférieur au coût actuel de production par groupes diesels qui est de l'ordre de 56¢/kWh. Le coût total du projet, incluant les travaux de relevés anémométriques et deux années de surveillance et de prise de mesures, est évalué à environ 600 000 $. De ce coût, Énergie, Mines et Ressources contribue 200 000 $. Si le projet est une réussite, Hydro-Québec se propose d'évaluer le potentiel éolien de 12 villages du grand nord québécois et d'y implanter des éoliennes pour un potentiel d'économie de 6 000 000 litres de pétrole par an.

Fort-Severn, Ontario

Hydro-Ontario a fait installé cet automne une éolienne de 65 kW fabriquée par la James Howden & Company représentée par Howden Group Canada. Cette éolienne sera reliée à un petit réseau diesel composé de 3 générateurs chacun ayant une capacité différente : 85 kW, 125 kW et 175 kW. Un nouveau système de contrôle a été développé de façon à pouvoir optimiser la production d'énergie produite par l'éolienne tout en suivant la demande de près et en maintenant l'efficacité des générateurs diesels. Une particularité de cette démonstration est que le "Groupe Howden" demeure propriétaire de l'éolienne pour une période de deux ans. À la fin de cette période, si l'éolienne a maintenu un certain niveau de fiabilité, l'Hydro-Ontario s'en portera acquéreur. Durant les deux premières années d'opération, le "Groupe Howden" récupérera une partie de son investissement en vendant l'énergie éolienne produite à l'Hydro Ontario au taux de 40¢/kWh. Ce projet d'une valeur approximative de 450 000 $ reçoit une contribution de 100 000 $ d'Énergie, Mines et Ressources.

Il y a plusieurs autres projets maintenant au stage de développement, ceux-ci verront probablement le jour durant l'année à venir.

Conclusion

Je vous ai présenté très brièvement les activités du gouvernement fédéral en matière d'énergie éolienne au niveau de la recherche et des programmes de démonstrations.

Dans le cadre du programme de recherche et de développement, on espère voir le développememt ou/et l'amélioration des produits canadiens.

Quant aux programmes de démonstration, ceux-ci aident à la commercialisation des produits sur le marché canadien. Dans la plupart des démonstrations, les réseaux électriques sont impliqués et, ceci leur permettra d'obtenir une expérience de plus avec l'énergie éolienne.

AEI-USDA WIND ENERGY PROGRAMS, 1985-1986

Vaughn Nelson and R. Nolan Clark*

Alternative Energy Institute, West Texas State University
*USDA, Agricultural Research Service, Bushland, Texas

INTRODUCTION

An update of the wind energy research programs for 1985-1986 of the Alternative Energy Institute (AEI) and the Conservation and Production Laboratory, Agricultural Research Service, USDA is presented as previous information was given last year at the meeting of Test Stations of SWECS (1). The research programs of USDA are: 1) evaluation of wind turbines for pumping irrigation water and 2) test site for the 500 kW VAWT designed by Sandia Laboratories. The programs of AEI are: 3) wind characteristics, 4) Wind Test Center, 5) research and development, and 6) education, feasibility studies, and consulting. AEI and USDA have had a cooperative research program since 1976 and personnel cooperate on all the projects except the Sandia project.

IRRIGATION

The pumping of irrigation water using wind power has been investigated from a number of aspects; wind assist-mechanical connection to electric motor and then to a diesel engine (2), wind assist-electrical connection (3), stand alone-mechanical connection, and stand alone-electrical connection (4). The present program consists of three projects for stand alone systems: an electric to electric connection using a Jacobs** wind turbine, mechanical connection using a DAF 4, and a new project which will look at low volume irrigation. This project will use the farm windmill and evaluate different ways to obtain a better load match to pumps.

500 kW, VAWT

USDA, Bushland, TX was selected as the test site for the 500 kW VAWT designed by Sandia Laboratories. Many of the components have been delivered and assembled. The torque tube will be erected this fall and rotated without the blades. Then next spring the blades will be attached and the evaluation will proceed.

** Manufacturers names are included for informational purposes only and do not imply an endorsement by USDA or AEI.

WIND CHARACTERISTICS

The data collection program (1978-1986) for a 100,000 sq km region from 9 stations in Northwest Texas and 1 station in Southeastern New Mexico has been completed. The data were initially collected at heights of 10 and 50 m. Later the 10 m stations were changed to 20 m and one station had an additional anemometer at 100 m. Day and night data were logged separately, except for 1 station. A catalog has been compiled which contains windspeed histograms, average windspeeds and average power densities, and wind shear exponents. There is a higher wind power potential at 50 and 100 m than would be predicted from data collected at 10 and 20 m. Also the wind shear exponent is larger at night, which means there is less diurnal variation at 50 and 100 m.

WIND TEST CENTER

At the Wind Test Center the PM Wind Power unit was dismantled since the company decided not to build any more wind turbines. The unit was given to AEI for their display collection for students and visitors. In August 1986, the rotor was lost on the UTRC unit due to a stress failure of the rotor hub shaft.

Besides the long term energy production and maintenance and operation, power curves were obtained for various modifications of the rotor and blades: blade roughness for the Carter 25, pitch and no tip brakes for the Enertech 21/5, different blades and different load on the inverter for the Hummingbird, and winglets on the UTRC (5). Blade roughness due to bugs and/or dirt degraded the performance as power is reduced 20 to 50 %. Similar effects have been noted on other wind turbines (6). Change of the pitch angle and coning angle on the Enertech 21/5 also changed the power curves. The power curves were similar for higher pitch angles in contrast to the change for every pitch setting for the Carter 25 (7). The tip brakes helped in yaw stability, especially with the smaller coning angles. The winglets on the UTRC improved the performance somewhat, but not significantly. Clearly there is a need for better aerodynamic performance predictions as the theory can not account for the variations seen in the experimental results.

A larger rotor (5.3 m versus 4.2 m diameter) with blades from Bergey were installed on the Hummingbird. As expected the power increased. However when the alternator was overloaded at low windspeeds by having the inverter cut in at 60 V rather than 150 V, the power curve was terrible. The load of the inverter has to be matched to the output of the wind turbine.

A one bladed unit manufactured by Riva Calzonia, Italy, was installed in July 1986 for evaluation. The unit is 5.3 m diameter, upwind with a yaw motor of 24 VDC. The rotor has a pitch control to the flat wise position for high rpm and a vibration and high windspeed sensor which yaws the unit 90 degrees out of the wind. The wind turbine was installed on the former PM tower which has a gin pole for service at ground level. The high rpm makes the unit very sensitive to the balance of the rotor. The unit was developed for charging batteries, but this one is connected to the utility line through an Acheval inverter.

RESEARCH AND DEVELOPMENT

Work has begun on a contract from the Solar Energy Research Institute to determine the elastic twist of blades of HAWTs. Blade structural properties for the Carter 250, ESI 54, and UTRC are to be determined and checked against the experimental results. A secondary goal is to verify and present a practical engineering methodology for the estimation of elastic twist on other wind turbine rotors. Dr. Stoddard of Pioneer Wind Power is one of the principal investigators on this project.

A power curve was obtained for a Sky Power 50 (15.2 m diameter, rated at 50 kW) which was located on a ranch near Claude, Texas. The unit has a toothed belt drive transmission, no gearbox.

EDUCATION AND INFORMATION

USDA and AEI have a number of visiting researchers who stay from a day to weeks. Besides presentations in the U.S., personnel from USDA and AEI gave presentations in Europe (8), Mexico (9), and China (10). Dr. Nelson spent three weeks in Sudan working on a USAID project on the feasibility of using renewable energy for pumping water in rural areas. There are also numerous written requests and telephone calls for information on wind energy.

SUMMARY

Work has continued on projects begun in previous years on irrigation pumping and evaluation of wind turbines. Three new projects were started and the wind data collection was completed.

REFERENCES

1. Vaughn Nelson, "Wind Energy Program, AEI and ARS," Proceedings, International Meeting of Test Stations of SWECS, Prince Edward Island, Canada, Aug 19-23, 1985.
2. R. N. Clark, "Co-Generation Using Wind and Diesel for Irrigation Pumping," ASAE Paper No. 84-2603, 1984.
3. R. N. Clark and F. C. Vosper, "Electrical Wind-Assisted Water Pumping," Journal of Solar Energy Engineering, 107, Feb 1985, p. 97.
4. F. C. Vosper and R. N. Clark, "Water Pumping with Autonomous Wind-Generated Electricity," Transactions of the ASAE, 28(4), p. 1305.
5. V. Nelson, K. Starcher, and W. Pinkerton, "AEI-Wind Test Center," presented at 1986 AWEA National Conference, Boston, MA, Sept 1-3, 1986.
6. Oded Yekutieli and R. Nolan Clark, "Influence of Blade Surface Roughness on the Performance of Wind Turbines," To be presented at 6th ASME Wind Energy Symposium, Dallas, TX, Feb 16-19, 1987.
7. V. Nelson, W. Pinkerton, R. N. Clark, "Power Variation with Pitch Setting for a Horizontal Axis Wind Turbine," Wind Engineering, Vol. 9, No. 2, 1985, p. 88.
8. R. Nolan Clark, "Wind Turbines for Water Pumping," DANWEA '86, Herning, Denmark, June 11-14, 1986.
9. Vaughn Nelson and Enrique Caldera M., "Wind Turbines in Latin America," IEEE/PES, 86 SM 471-7, Mexico City, Mexico, July 20-25, 1986.
10. Vaughn Nelson and R. Nolan Clark, "Wind Turbine Applications," International Conference on Solar and Wind Energy Applications, Beijing, China, Aug 3-6, 1985.

WIND ENERGY ACTIVITIES IN SWEDEN

Staffan Engström

National Energy Administration, Sweden
S-117 87 Stockholm
Tel 0046-8-744 95 00

The Government-funded wind energy program in Sweden was initiated in 1975 and has been concentrated on the development and evaluation of two large WECS, Maglarp 3 MW and Näsudden 2 MW. Following the evaluation of the program in late 1984 and the Government Energy Bill in 1985, the Swedish utilites are forming a development company for wind energy that together with Government funds will finance of medium scale WECS and design studies on multimegawatt WECS. Further evaluation of the Maglarp and Näsudden WECS will also be carried out together with other research activites in the Government-funded 1984-87 wind energy research program

The national Swedish wind energy program was initiated in 1975 and an evaluation of the main results of the ten year program was published in early 1985. (1, 2) It has been presented at earlier conferences. (3) Here a general description of wind energy activities and plans in Sweden since then will be given.

WECS Prototypes Maglarp and Näsudden

The two prototype WECS Maglarp and Näsudden now have been in service for some years. They have roughly the same turbine diameter, 78 and 75 meter respectively. The output of the generators is 3 and 2 MW. In August 1986 the Maglarp turbine had collected 14.2 GWh during 9 550 operational hours. The figures for Näsudden were 5.7 GWh and 5 350 hours.

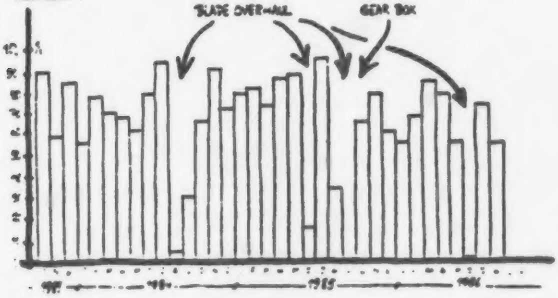


Figure 1. Time availability for Maglarp WECS for the period October 1983 - August 1986.

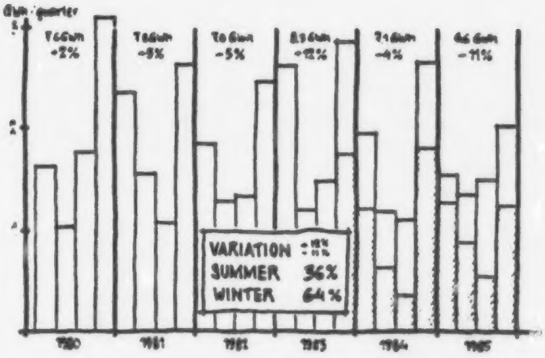


Figure 2. Available energy in Maglarp 1980 - 1985. The hatched areas show the real electricity production.

The time availability of the Maglarp prototype has been quite high, with most months better than 70 %, since the operation was taken over by the Sydkraft utility in September 1983. Each summer considerable time has been spent on blade surface maintenance, with repair of the lightning protection beeing the most time consuming element. It consists of patches of aluminum foil glued to the blade surface. It cracks, erodes and gets burns by each lightning impact. In the summer of 1986 the decision was taken to remove the lightning protection from the outer 15 % of the blades, as a full scale test whether it was needed or not. The experiences so far are quite promising, since several lightning strikes have hit the remaining "protected" areas since then but no damage has occured to the unprotected tips. When the measurement program is completed, and thus the wiring for the strain gauges in the blades can be removed, a complete removal of the lightning protection of the blades is planned.

In the summer of 1986 a damage in the teether bearings was discovered. Since it is evident that these roller bearings can not get proper lubrication due to the very small movements, a few degrees, the intention is to replace them with elastomeric bearings. In order not to increase the damage until new bearings can be installed. the maximum power has been temporarily reduced to 1.5 MW

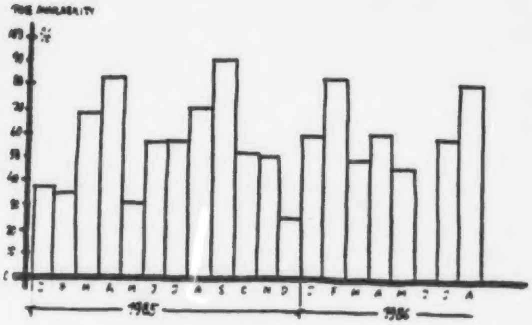


Figure 3. Time availability for Näsudden WECS for the period January 1985 - August 1986.

Due to an early gearbox failure, the Näsudden WECS did not start routine operation until May 1984. In 1986 the availability has increased considerably with some months exceeding 90 %. The main reasons for the earlier low availabilty have been minor problems, e.g. a troublesome slip ring assembly.

In July this year a small crack at 30 % radius in the load carrying steel spar of one blade was repaired by welding. The repair seems to have been successful but the event demonstrates that the spar is heavily stressed and indicates that the remaining life might be considerably less than the demanded 30 years.

More results from the evaluation of Maglarp and Näsudden have been presented during this conference, in papers by other authors. Also the Basic Research Program is financed by the National Energy Administration of Sweden and has resulted in a number of papers at this conference.

Future Wind Energy Program

The evaluation of the Swedish Wind Energy Program had some impact on the Government's Bill on Future Energy Policy, which was accepted by Parliament in June 1985. It stated, among other things, that the Wind Energy R&D program shall continue, which it does at a level of ca SEK 67 Million for the 1985-87 period and that the utilities shall carry a main responsibility for the wind power installations necessary to carry on the development of wind power in Sweden. As the utilities were not likely to assume this responsibility by themselves, the Minister of Energy initiated talks which in October 1985 resulted in an agreement between the Government and the National Energy Administration on one side and the utilities on the other. It means, that the utilities in the 1985-87 period will conduct a conceptual design study of megawatt-size WECS, which will make full use of the lessons learned at Maglarp and Näsudden. It shall result in a firm bid on a new prototype design. The utilities also will buy a commersially available WECS in the 0.7-1.0 MW size range. For these purposes the utilites - Vattenfall, Sydkraft and Svenska Kraftverksföreningen - have formed a special company, Kraftföretagens Vindkraft AB (The Utilities Wind Power Co). In the "package" further evaluation of Maglarp and Näsudden and some modifications of the Näsudden WECS, also are included. The total cost is SEK 42 million of which the utilities bear one half.

In the immediate plans there is also a ø 50 m turbine diameter, 1.5 MW advanced WECS project proposed by Scanwind, a company owned by 3K Engineering, Uddevalla Invest, Swedyards and Danish Wincon. It utilizes some of the main components from the former Swedeyards WTS 1200 project, but differs in that it is fixed-pith, variable speed and yaw control. The main decisions regarding the financing of the project are expected in the near future.

For the 1987-90 period there is a proposal regarding future R&D work in wind energy at a level of SEK 15 million/yr, ie roughly the same level as the ongoing program.

Siting investigation

In the Government Energy Bill of 1985 there was also a proposal regarding a siting investigation for wind power. It shall propose sites for 10 TWh/yr on shore and 20 TWh/yr off shore. The first report is expected in early 1987 and the final report one year later. At the moment talks are conducted with the regional authorities regarding the selection of areas. Within the investigation a new estimate of the total potential for on shore wind power in Sweden has been made. The new preliminary estimate is 74 TWh/yr, which is considerably more than in the previous investigation. The figure assumes a distance of 300 m to the closest building. If the distance is increased to 500 m the protential decreases to 36 TWh/yr. The work covers areas with an energy content in the wind of 4-8 MWh/m^2.yr at 100 m height.

European cooperation

Recently initial discussions have been conducted with Italy and the Federal Republic of Germany regarding possible cooperation in the development of large WECS. Further talks will be conducted during the fall of 1986.

References:

1. S. Engström: Wind Energy Activities in Sweden. Paper presented at Wind Power 85, August 27-30, 1985, San Francisco, Ca.

2. Wind Power. National Energy Administration, Sweden, 1985:1 (In Swedish, summary in English).

3. Wind Energy in Sweden. Brochure. National Energy Administration, Sweden, 1986.

INDEX BY AUTHOR

PAGE

Arseneault, Jean Marc 279
Baker, David 189, 415
Beausoleil, G.H. 313
Brothers, Carl 229, 415
Carpentier, Monique 435
D'Amours, Alban 289
Drewes, Per 309
Edworthy, Jason 135
Engström, Staffan 449
Ereaux, John 373
Fraunié, Philippe 203
Gray, Tom 47
Hoffman, David 249
Hume, D. 309
Hylander, J. 123
Johnson, Dale 5
Kentfield, J.A.C. 175
Malcolm, D.J. 367
Massé, Bernard 107
Miller, H.D. 425
Nelson, Vaughn 445
Noël, Jean Marc 391
Paraschivoiu, Ion 83
Passmore, Jeff 51
Pastorel, H. 65
Penna, Paul 381
Reid, Réal 329
Salmon, J.R. 253
Schiller, E.J. 159
Shalaby, Amir 37
Shepherd, J.C. 19
Shokr, Mohamed 267
Strange, Don 1
Weir, Brian 409

ATTACHMENTS

LIST OF ATTENDEES

Canadian Wind Energy Conference '86

LIST OF ATTENDEES

Azeddine Allet
Ecole Polytechnique
Case Postale 6079
Succursale A
Montreal PQ
H3C 3A7

David Argue
Passmore Associates Int'l.
#209-135 York St.
Ottawa ON
K1N 5T3
(613)234-3602

Jean-Marc Arseneault
Laval University
Quebec PQ
(418)656-2199

David Baker
DRB Engineering
116 Hankwood Way
Calgary AB
T3G 1X4
(403)239-4100

Elliott Bayly
WhirlWind Power Company
207 1/2 East Superior Street
Duluth MN
55802
(218)722-1492

Louis Beaulieu
President
Sambrabec Inc.
5756 Ave. Deom
Montreal PQ
H3S 2N4
(514)738-7241

Gilles H. Beausoleil
Ingenieur en Electricite
Shawinigan Consultants
Div. of Lavalin Inc.
1100 Ouest, Boul. Dorchester
Montreal PQ
H3B 4P3
(514)871-1020

Daniel Bedard
#6-930 de Bourgogne
Ste-Foy PQ
G1E 3E3

Steve Bloomer
Incentives Officer
D.R.I.E.
#4840-1 First Canadian Pl.
Toronto ON
M5X 1B1
(416)365-3731

Martial Bouchard
Martial Bouchard Inc.
Box 684
Alma PQ
G8B 5W1
(418)668-5674

Carl Brothers
Manager
Atlantic Wind Test Site
Box 189
Tignish PEI
C0B 2B0
(902)882-2746

Don Buchan
Buchan, Lawton, Parent Ltd.
5370 Canotek Road
Ottawa ON
K1J 8X7
(613)748-3762

Real Carbonneau
Quebec Dept. of Energy
8 Cook Street, 2nd Floor
Quebec City PQ
GlR 5H2
(418)643-2109

Jean Paul Cariou
Information Officer
Energy, Mines & Resources
580 Booth Street
Ottawa ON
KlA 0E4
(613)995-3065

Monique Carpentier
Technology Coordinator - Wind
Energy Mines & Resources
460 O'Connor
4th Floor
Ottawa ON
KlA 0E4
(613)995-9447

Subhash Chander
Health & Welfare Canada
Jeanne Mance Bldg.
Room 645
Ottawa ON
KlA 1B4
(613)990-7995

Jack T. Cole
Energy Mines & Resources
460 O'Connor Street
9th floor
Ottawa ON
KlS 5H3
(613)995-9447

Donald F. Coleman Jr.
Director of Marketing
Nordtank Inc.
860 Via De La Paz, Suite D3
Pacific Palisades CA
90272
(213) 459-8543

David Connelly
Dir. of Finance
CTM Ltd.
#600-2 St. Clair Ave. W.
Toronto ON
M4V 1L7
(416)961-0605

Helene Connor Lajambe
C.R.E.D.I.T.
U. of Quebec
Box 8888
Succursale A
Montreal PQ
H3C 3P8
(514)653-2925

Alban D'Amours
Associate Deputy Minister
of Energy
Province of Quebec

J. Dickenson
Dept. de Genie Mech.
University Laval
Cite Universite PQ
GlK 7P4
(418)656-2414

Per Drewes
Ontario Hydro
700 University Avenue
Hll C20
Toronto ON
M5G 1X6
(416)592-2928

Andre Drolet
Hydro Quebec
5200 Boul. Neuvialle
Quebec PQ
GlK 7Kl
(418)843-7359

J. Ereaux
Adecon Energy Systems
32 Rivalda Road
Weston ON
M9M 2M3
(416)745-2416

Graham French
Energy, Mines & Resources

David Gilmer
Sales Manager
Wincon Energy Systems Inc.
RR 1, Box 677
Foliage View
West Lebanon NH
03784
(603)448-5133

Thomas O. Gray
Executive Director
American Wind Energy Assoc.
1017A King Street
Alexandria VA
22314
(703)684-5196

Le-Huy Hoang
Professor
Univ. du Quebec
3351 Blvd. Des Forges
Trois-Rivieres PQ
G9A 5H7
(819)376-5071

David Hoffman
CanWEA
44A Clarey Ave.
Ottawa ON
K1S 2R7
(613)234-9463

Debra S. Hrynkiw
Thermax Energy Systems
39 Main Street
Vankleek Hill ON
K0B 1R0
(613)678-3322

Duncan Hume
Corporate Development
Howden Group Canada Ltd.
1510 Birchmount Road
Scarborough ON
M1P 2G6
(416)752-7310

J. Hylander
Dept. of Electrical Machines
and Power Electronics
Chalmers U. of Technology
S - 412 96
Goteborg SWEDEN
+46-31 81 01 00

Walter T. Jackson Jr.
Sr. Research Engineer
University of New Mexico
N.M. Engineering Res. Instit.
Box 25
Albuquerque NM
87131
(505)766-8006

Yves Jean
Laval University
Quebec PQ
(418)656-2199

Dale Johnson
President
Wind Power Inc.
Box 1137
208 Stockton Avenue
Okotoks AB
T0L 1T0
(403)938-5500

Mary-Ellen Jones
Director
Alberta S.P.F.A.
Box 3749
High River AB
T0L 1B0
(403)652-4888

J. Kentfield
Mechanical Engineering
University of Calgary
2500 University Dr. N.W.
Calgary AB
T2N 1N4
(403)220-5771

Colin C. Kerr
Vice President Engineering
Thermax Energy Systems
39 Main Street
Vankleek Hill ON
K0B 1R0
(613)678-3322

Keniji Kitano
Manager
SUMITOMO Heavy Industries
Suite 3669
One World Trade Centre
New York NY
10048
(212)432-0572

Juergen K. Kleta
Dir., Energy Conservation
Alta. Dept. of Energy
2nd Floor, Pacific Plaza
10909 Jasper Ave.
Edmonton AB
T5J 3M8
(403)427-8042

Vincent P. Lacey
Product Manager, VAWT
Indal Technologies Inc.
3570 Hawkestone Road
Mississauga ON
L5C 2V8
(416)275-5300

Matthieu P. Lavallee
Hydro Quebec
Place Dupuis
855 rue St. Catherine est
Montreal PQ
H2L 4P5

Tom Ledwell
Energy Mines & Resources
460 O'Connor Street
9th floor
Ottawa ON
K1S 5H3
(613)995-9447

Malcolm Lodge
Wind Program Manager
Resource Ventures Inc.
49 Pownal Street
2nd Floor
Charlottetown PEI
C1A 3W2
(902)892-0361

David Malcolm
Structural Engineering Mgr.
Indal Technologies Inc.
3570 Hawkestone Road
Mississauga ON
L5C 2V8
(416)275-5300.

Louis Marmen
Energy, Mines & Resources

Bernard Masse
Chercheur
IREQ
1800 Montee Ste-Julie
Box 1000
Varennes PQ
J0L 2P0
(514)652-8271

Robert McConnell
Section Manager
Solar Energy Research Instit.
1617 Cole Blvd.
Golden CO
80401
(303)231-1019

H. David Miller
Manager-Marketing Services
TransAlta Utilities
Box 1900
Calgary AB
T2P 2M1
(403)267-7182

Lawrence H. Mott
Sales Engineer
NRG Systems
1955 Church Hill Rd.
Charlotte VT
05445
(802)425-3468

Paul J. M. Nelissen
Vice-President
STORK Fans
P.O. Box 3386
Princeton NJ
08540
(609)921-3907

Vaughn Nelson
Director
Alternative Energy Institute
Box 248
W. Texas State University
Canyon TX
79016
(806)656-3904/3915

Jean-Marc Noel
Technical & Sales Manager
AEROWATT INTERNATIONAL
6, avenue des Coquelicots
94385 BONNEUIL Cedex FRANCE
(1)43.39.78.83

Jane Oliver
Energy, Mines & Resources
460 O'Connor Street
Ottawa ON
K1A 0E4
(613)995-9447

I. Paraschivoiu
Associate Prof., Mech. Engin.
Ecole Polytechnique
Case Postale 6079
Succursale A
Montreal PQ
H3C 3A7
(514)340-4583

D. jeffrey Passmore
President
Passmore Associates Int'l.
135 York Street
Suite 209
Ottawa ON
K1N 5T4
(613)234-3602

Henri Pastorel
Chercheur
IREQ
1800 Montee Ste-Julie
Box 1000
Varennes PQ
J0L 2P0
(514)652-8271

Anthony Pau
President
Anthony Pau & Associates
564 Victoria Park Ave.
Toronto ON
M4E 3T5
(416)698-5664

Paul Penna
Low Speed Aero Lab
Nat'l. Research Council
Montreal Road, M-2, LSAL
Ottawa ON
K1A 0R6
(613)993-0489

Jean Luc Perron
President
EOLBEC INC.
635 rue 30ieme
St. Georges ouest
Beauce PQ
G5Y 4H5
(418)228-8412

Stelios Pnevmaticos
Chief, Solar Energy Program
Energy Mines & Resources
Renewable Energy Div.
460 O'Connor Street
Ottawa ON
K1S 5H3
(613)995-9447

Alexander Printzios
President
Adecon Energy Systems
32 Rivalda Road
Weston ON
M9M 2M3
(416)745-2416

Raj Rangi
Head - Wind Energy R & D
Nat'l. Research Council
Room 115, Bulding M-2
Montreal Road
Ottawa ON
K1A 0R6
(613)993-9127

Alex Redekopp
Sr. Program Officer
Health Sciences Division
Int'l. Devel. Research Centre
Box 8500
Ottawa ON
K1G 3H9
(613)236-6163

Real Reid
Ingenieur d'Essais
IREQ
1800 Montee Ste-Julie
Box 1000
Varennes PQ
J0L 2P0
(514)652-8254

Guy Roberts
#51-335 Cooper Street
Ottawa ON
K1P 0G6
(613)232-1129

Robert A. Rouleau
Hydro Quebec
5200 Boul. Neuvialle
Quebec PQ
G1K 7K1
(418)843-7403

Joe Saab
Advisor, Energy Prog. & Tech.
Ont. Ministry of Energy
56 Wellesley St. W.
Queen's Park
Toronto ON
M7A 2B7
(416)965-0463

James R. Salmon
Atmospheric Environment
Environment Canada
24 Heslop Drive
Toronto ON
M4W 4R1
(416)255-5849

Bernard Saulnier
Chercheur
IREQ
1800 Montee Ste-Julie
Box 1000
Varennes PQ
J0L 2P0
(514)652-8859

Eric J. Schiller
Associate Professor
University of Ottawa
Civil Engineering
770 King Edward Street
Ottawa ON
K1N 9B4
(613)564-2258

Bill Schwankle
American AeroStar Sales
P.O. Box 704
1200 Bruce Street
Crookston MN
56716
(218)281-2065

Farrell Smith Seiler
Executive Editor
Wind Energy News Service
P.O. Box 4008
St. Johnsbury VT
05819
(802)748-2425

Amir Shalaby
Supply Planning Division
Ontario Hydro
700 University Avenue
Toronto ON
M5G 1X6
(416)592-7148

Jay C. Shepherd
Blaney McMurtry Stapells
Box 14
Suite 1400, 20 Queen St. W.
Toronto ON
M5H 2V3
(416)593-1221

Robert W. Sherwin
President Elect
American Wind Energy Assoc.
P.O. Box 1097
Norwich VT
05055
(802)649-5183

Mohamed Shokr
Atmospheric Environment Servic
Environment Canada
4905 Dufferin Street
Downsview ON
M3H 5T4
(416)667-4910

Jeffrey Siegel
Bonus Energy Inc.
112 Canterbury Road
White Plains NY
10607
(914)997-0775

Rick Smith
Atlantic Wind Test Site
R.R. 4, Tignish
North Cape PEI
C0B2B0
(902)882-2746

Paul Stothart
DRIE
235 Queen
7th Floor East/GMEE
Ottawa ON
K1A 0H5

Don Strange
Director, Renewable Energy Div
Energy Mines & Resources
460 O'Connor Street
Rm. 619
Ottawa ON
K1S 5H3
(613)995-9447

George Tadros
Energy Sector, CIDA
Hull PQ
K1A 0G4

John Te Raa
Operations Manager
P.E.I. Energy Corp.
Box 2000
Charlottetown PEI
C1A 7N8

R. Jack Templin
Head - Low Speed Aero Lab
Nat'l. Research Council
Bldg. M-2
Montreal Road Lab
Ottawa ON
K1A 0R6
(613)993-2423

Tim Terris
Engineer
CTM Ltd.
#600-2 St. Clair Ave. W.
Toronto ON
M4V 1L7
(416)961-0605

Daniel Tokateloff
Energy, Mines & Resources
Montreal PQ

Philippe Viarouge
Dept. de Genie Electrique
Laval University
Ste-Foy PQ
G1K 7P4
(418)656-2199

David E. Ward
General Manager
Nordtank Inc.
6421 South Front Road
Suite B
Livermore CA
94550
(415)449-6688

Albert Watts
Chef de Service
IREQ
1800 Monte St-Julie
Varennes PQ
J0L 2P0
(514)652-8388

Brian Weir
Canadian Standards Assoc.
178 Rexdale Blvd.
Rexdale ON
M9W 1R3
(416)747-4363

Robert Yelle
Information Officer
Energy, Mines & Resources
580 Booth Street
Ottawa ON
K1A 0E4
(613)995-3065

S. von Zweygbergk
Dept. of Electric Machines
and Power Electronics
Chalmers U. of Technology
Fack S-402 20
Goteborg SWEDEN
+46 031-81 01 00

LIST OF EXHIBITORS

Canadian Wind Energy Conference '86

LIST OF EXHIBITORS

Atlantic Wind Test Site
Box 189
Tignish, P.E.I.
C0B 2B0
(902) 882-2746

Bonus Energy Inc.
112 Canterbury Road
White Plains, NY
10607
(914) 997-0775

Energy, Mines and Resources Canada
580 Booth St.
Ottawa, Ont.
K1A 0E4
(613) 995-9447

Howden Group Canada Ltd.
1510 Birchmount Road
Scarborough, Ont.
M1P 2G6
(416) 752-7310

INDAL Technologies Ltd.
3570 Hawkestone Road
Mississauga, Ont.
L5C 2V8
(416) 275-5300

NRG Systems Inc.
1955 Church Hill Road
Charlotte, VT
05445
(802) 425-3468

WhirlWind Power Company
207 1/2 East Superior St.
Duluth, MN
(218) 722-1492

MINUTES OF CANWEA SECOND ANNUAL MEETING

CANADIAN
WIND ENERGY
ASSOCIATION

44A Clarey Avenue
Ottawa, Ontario, K1S 2R7
(613) 234-9463

MINUTES OF
THE ANNUAL GENERAL MEETING OF THE
CANADIAN WIND ENERGY ASSOCIATION
HELD AT
QUEBEC CITY ON OCTOBER 27, 1986 AT 5:00 P.M.

Minutes:

The following directors were present at the meeting:

Alex Printzios	- President
Albert Watts	- Treasurer
Vince Lacey	- Secretary
Mary Ellen Jones	- Vice-President
Malcolm Lodge	

Introduction

A. Printzios called the meeting to order and introduced the Board of Directors.

M. Lodge wrote the agenda on the display board at the front of the room. A. Printzios asked the membership if there were any requests for additions to the agenda and none were requested.

A. Printzios briefly summarized the minutes of the 1984 Annual General Meeting.

President's Report

A. Printzios reviewed CANWEA's activity for 1986.

CANWEA filed an application for CANWEA to be given non-profit status.

David Hoffman was appointed as Office Manager and CANWEA's permanent office location was established in Ottawa.

David Hoffman produced and continues to produce the CANWEA quarterly newsletter.

CANWEA continued its membership in the Conservation/Renewable Energy Industry Council and CANWEA attended meetings with senior officials of the Department of Energy, Mines and Resources.

CANWEA planned a role in having wind turbine generators qualify for inclusion in Class 34.

At the request of the National Research Council, CANWEA has provided a director to sit on the Board of Directors of the Atlantic Wind Test Site. This position is to provide input to the Board from the industry.

CANWEA continued to expand its contacts with international organizations such as the American Wind Energy Association and co-sponsored the Great Plans Wind Energy Conference in Minnesota.

An aggressive membership drive which was undertaken was not as successful as hoped. The number of corporate members is now less than in 1985. More effort is required here.

Comments/Questions and Answers

Jeff Passmore congratulated CANWEA on its role in having wind turbine generators included in Class 34, but suggested that the lobbying effort continue because Class 34 is under revision by the Government. A. Printzios responded saying the next step was to convince utilities that wind energy was beneficial to all.

A. Printzios called for a motion to accept the President's report. Carl Brothers' motion for acceptance was seconded by J. Shepherd.

Treasurer's Report

A. Printzios tabled and discussed the "Summary of Operating Revenues and Expenditures" (copy attached) for the period ending December 31, 1985.

Carl Brothers asked where the $10,000. revenue for the proceedings came from. A. Printzios advised that NRC had provided this.

A. Printzios tabled and discussed the "Cash Balance of September 30, 1986."

R. Rangi asked if CANWEA had solicited utilities to become corporate members. A. Printzios responded that CANWEA had not been very successful in this effort.

J. Shepherd made a motion to accept the Treasurer's Report which was seconded by C. Brothers.

1987 Budget

Albert Watts tabled and discussed the "1987 Budget" (copy attached).

Duncan Hume asked if Energy, Mines and Resources (EMR) had indicated they would provide financial support for CANWEA in 1987. A. Printzios responded that EMR had supported CANWEA in 1985 and 1986 and as such it looked hopeful that this would continue in 1987.

Carl Brothers asked where the $10,000. revenue for the proceedings would come from. M. Lodge responded that CANWEA would be looking for a new sponsor since NRC could no longer fund this.

Real Reid's motion for acceptance of the 1987 Budget was seconded by Bernard Saulnier.

Atlantic Wind Test Site Board Member

A. Printzios asked the membership to elect a CANWEA member to sit on the Board of Directors of the Atlantic Wind Test Site. J. Shepherd suggested that the CANWEA Board of Directors should appoint someone. It was concluded that the appointment was a CANWEA Board decision.

Election of Directors

A. Printzios read the current CANWEA voting members list and provided time for lapsed members to renew prior to the election.

M. Lodge explained that only voting members could be nominated to serve on the Board of Directors.

Dave Baker asked if nominations would be accepted for persons not in attendance. M. Lodge responded that this would be acceptable only if there was a reasonable assurance that the nominee would accept.

M. Lodge advised that CANWEA's Nominations Committee was nominating Real Reid and then called for nominations from the floor:

Nominee	**Nominated by**	**Seconded by/Declined**
Jay Shepherd	Alex Printzios	Duncan Hume
Duncan Hume	Collin Kerr	declined
Collin Kerr	Alex Printzios	declined
Dale Johnson	Jeff Passmore	Vince Lacey
Jason Edworthy	Collin Kerr	Vince Lacey
Dave Baker	Vince Lacey	declined
Carl Brothers	John Ereaux	Real Reid

M. Lodge declared the nominations closed.

David Hoffman and David Argue were appointed as scrutineers.

The newly elected Directors were Real Reid and Jay Shepherd.

V. Lacey's motion to destroy the ballots was seconded by Carl Brothers.

New Business

Dave Baker advised that if the 1987 Conference was held in Lethbridge, the Alberta Department of Agriculture and the Lethbridge Wind Test Site were prepared to provide organization services at cost to CANWEA. M. Lodge responded that both Calgary and Lethbridge were being considered for the 1987 Conference.

Jay Shepherd's motion for adjournment was seconded by Real Reid.

Vince Lacey

Vince Lacey,
Secretary

**CANADIAN
WIND ENERGY
ASSOCIATION**

44A Clarey Avenue
Ottawa, Ontario, K1S 2R7
(613) 234-9463

SUMMARY OF OPERATING REVENUES AND EXPENDITURES

(For the year ending December 31, 1985)

REVENUES	$40,050.14
EXPENDITURES	26,654.63
BALANCE	$13,395.51

Prepared by: ______________________
Treasurer

CANADIAN WIND ENERGY ASSOCIATION

REVENUE

(relating to period ending December 31, 1985)

1. **MEMBERSHIP FEES**		
Corporate	$ 3,300.00	
Associate	300.00	
Member	210.70	
Student	10.00	$ 3,820.70
2. **EM&R FACT SHEET PREPARATION**		
Phase I	2,975.00	
Phase II	2,975.00	5,950.00
3. **CANWEA CONFERENCE 1985**		
Registrations	6,679.44	
Exhibitors	1,600.00	
Conference Proceedings	10,000.00	
EM&R Contribution	12,000.00	30,279.44
TOTAL REVENUE		$40,050.14

EXPENDITURES

1. **OFFICE EXPENSES**		
Telephone	$ 522.63	
Postage	53.09	
Photocopying	89.70	$ 665.42
2. **PUBLICATIONS**		
Newsletter	1,500.00	1,500.00
3. **MEMBERSHIPS**		
Conservation/Renewable Energy Industry Council	400.00	400.00
4. **SPECIAL PROJECTS**		
EM&R Fact Sheet Phase I	2,400.00	
EM&R Fact Sheet Phase II	2,450.00	
Travel Expenses	382.00	5,232.00
5. **TRANSPORTATION**		
Travel Expenses	381.50	381.50
6. **OTHER EXPENSES**		
Bank Charges	7.50	7.50
7. **CANWEA CONFERENCE 1985**		
Hotel Expenses	2,709.92	
Organizational Expenses	10,752.70	
Audio-Visual Aids	119.84	
Awards	82.39	
Conference Proceedings	3,988.04	17,652.89
8. **INCORPORATION FEES**		
Scales, Jenkins & McQuaid	815.32	815.32
TOTAL EXPENDITURES		$26,654.63

**CANADIAN
WIND ENERGY
ASSOCIATION**

44A Clarey Avenue
Ottawa, Ontario, K1S 2R7
(613) 234-9463

CASH BALANCE

(as at September 30, 1986)

1985 (per summary)	$ 13,395.51
1986 (nine months)	(3,071.26)
	10,324.25

CASH AT BANK	7,624.25
PETTY CASH	300.00
RECEIVABLES (OME)	2,400.00
	10,324.25

**CANADIAN
WIND ENERGY
ASSOCIATION**

44A Clarey Avenue
Ottawa, Ontario, K1S 2R7
(613) 234-9463

REVENUE

(relating to the nine month period to September 30, 1986)

1. MEMBERSHIP FEES		
Corporate	$ 300.00	
Associate	205.37	
Member	485.56	$ 990.93
2. CANWEA NEWSLETTER		
Ontario Ministry of Energy	5,400.00	5,400.00
TOTAL REVENUE		$ 6,390.93

**CANADIAN
WIND ENERGY
ASSOCIATION**

44A Clarey Avenue
Ottawa, Ontario, K1S 2R7
(613) 234-9463

EXPENDITURES

(relating to the nine month period to September 30, 1986)

1. **OFFICE EXPENSES**		
Administration and Rental	1,500.00	
Telephone, Postage, Photocopying	123.43	1,623.43
2. **PUBLICATIONS**		
Newsletter		2,700.00
3. **CANWEA CONFERENCE 1986**		
Organizational Expenses		5,059.48
4. **OTHER EXPENSES**		
Bank Charges	5.00	
Corporations Branch Annual fees	30.00	
Notarized copies of Charter	44.28	79.28
TOTAL EXPENDITURES		$ 9,462.19

CANADIAN
WIND ENERGY
ASSOCIATION

44A Clarey Avenue
Ottawa, Ontario, K1S 2R7
(613) 234-9463

SUMMARY OF OPERATING REVENUES AND EXPENDITURES

(for the nine months' period ending September 30, 1986)

REVENUES	$ 6,390.93
EXPENDITURES	9,462.19
BALANCE	$ (3,071.26)

Prepared by: ______________________

CanWEA Budget - 1987

The CanWEA Directors met on October 14, 1986 in Ottawa to plan and develop the Association business. An annual budget for 1987 was prepared and is presently below:

Expenditures		1987	
Operating			
Quarterly Newsletter à $1500/issue		$ 6,000	
Administration			
Office Rental		1,200	
Secretarial/Clerical		1,200	
Office Supplies		1,600	
Industry Council Membership		400	
Telephone		1,200	
Directors Expenses and Travel		3,700	
Contingency and Miscellaneous		1,000	
	Subtotal		$16,300
Special Projects			
OME Workshop		4,000	
	Subtotal		$ 4,000
Conference Expenditures			
Organizing Subcontractor		19,000	
Organizing Travel		5,000	
Conference Space		2,700	
Translation		500	
Proceedings		3,000	
Miscellaneous		1,000	
	Subtotal		$31,200
GRAND TOTAL EXPENDITURES			$51,500

Revenue

Memberships			
Students $ 10.		50	
Member $ 30.		600	
Associates $100.		500	
Corporate $300.		3,600	
	Subtotal		$ 4,750
OME Workshop		4,000	
Sale of Proceedings		10,000	
	Subtotal		$14,000
Conference Income			
Delegates 50 x $150		7,500	
Exhibitors 10 x $300		3,000	
	Subtotal		$10,500
OME Newsletter and Workshop Contribution			$10,000
GRAND TOTAL REVENUE			$39,250
Budget balance December 31, 1987			($12,250)
Proposed EMR Operating Grant		12,000	
Proposed Provincial Contribution		7,500	
Cash on hand (Dec. 31, 1986)		3,500	
	Subtotal		$23,000
Balance December 31, 1987 (estimated)			$10,750

Albert Watts,
Treasurer,
23 October, 1986.

MINUTES OF CANWEA DIRECTORS' MEETING

CANADIAN
WIND ENERGY
ASSOCIATION

44A Clarey Avenue
Ottawa, Ontario, K1S 2R7
(613) 234-9463

MINUTES OF DIRECTORS MEETING

OCTOBER 27, 1986

Present at the meeting were Mary-Ellen Jones, Malcolm Lodge, Vince Lacey plus the two newly elected Directors, Real Reid and Jay Shepherd. Alex Printzios waived his right to attend.

Conference

It was agreed by all that the 1987 CANWEA Conference would be held in Calgary or Lethbridge in September or October of 1987. The three parties interested in organizing the conference were identified as Nor'Wester Energy Systems, Passmore and Associates, and the Lethbridge Wind Test Center. Mary-Ellen Jones expressed interest on behalf of the Small Power Producers Association of Alberta in co-sponsorship of the Conference.

It was agreed that V. Lacey would prepare a request for proposals for review by all of the Directors prior to sending it to the three possible proponents.

Proceedings

It was agreed by all that a new sponsor must be found to financially support the printing and distribution of the conference proceedings.

Post NCAI Position Paper

It was agreed by all that CANWEA must prepare a position paper to present to the Department of Energy, Mines and Resources.

Election of Officers

A. Printzios had previously offered his resignation as the President, which was accepted. A. Watts has previously resigned as Treasurer, which was accepted.

Nominations for Officers were made:

Nominee	Position	Nominated By	Seconded by
V. Lacey	President	R. Reid	M. Lodge
M.E. Jones	President	V. Lacey	J. Shepherd

V. Lacey was elected President.

V. Lacey nominated M.E. Jones as Treasurer. This was seconded by R. Reid and accepted by M.E. Jones.

V. Lacey nominated J. Shepherd as Secretary. This was seconded by R. Raid and accepted by J. Shepherd.

V. Lacey nominated R. Reid as Vice-President, which was seconded and accepted.

The meeting was adjourned.

Vince Lacey

....

Vince Lacey,
Secretary.